ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

STREAM OF EXPLORATION GEOPHYSICS

GEOPHYSICAL INVESTIGATIONS FOR GROUND WATER EXPLORATION IN LEGEDADI, ADDIS ABABA ETHIOPIA

By

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A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES IN PARTIAL FULFILLMENTS OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN EXPLORATION GEOPHYSICS

Jun, 2013

Addis Ababa, Ethiopia.

ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES
DEPARTMENT OF EARTH SICENCE

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Acknowledgments

Above all, I would like to thank the almighty; God, for letting me accomplish this stage.

I am deeply indebted to Dr.tigistu Haile and Dr. Tilahun Mamo, my advisors, for their many suggestions and constant support and friendly approach during this research.

My sincere thanks is addressed to my Family and my intimate Friends. They are the hero of my success without their push and support, this stage was unthinkable. I have derived materials from many research books, and am indebted to the authors of those publications and books and to Ato Engida Wendimagegn and Ato Yigrem for their huge advice and help.

I would like to mention and thank everyone who offered help and support in one way or another, during the entire period of my study. I offer special thanks to my brother Dr. Atakalti Belay who is everything for me.

Abstract

In this thesis, Geophysical investigating for ground water exploration were carried out at Legedadi, Addis Ababa, Ethiopia. The methods employed were electrical vertical electrical sounding, and magnetic mapping survey. The thesis work mainly focuses on the evaluation of the deep groundwater potential in order to identify the potential area for groundwater and indicate the most promising sites of waterways for drilling capable of supplying potable water on continuous basis.

On this work the conducted vertical electrical sounding was processed by using different soft wares and from that apparent resistivity pseudo-section, resistivity inversion curves, 2D-depth model, apparent resistivity contour and also layer thickness depth, were done. And the magnetic model was also processed by using software's and from it grid map, trend map, analytic map, vertical and horizontal derivative map, magnetic intensity model etc. was done. These results were correlated and interpreted and additional geological information was acquired. Generally the result obtained was interpreted based on in geophysical and geological languages. Finally conclusions and recommendations are given.

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CHAPTER -1

1 INTRODUCTION

1.1 General

Earth has been described as a "blue marble." It looks like the watery planet that it is. Water is a vital substance that sets Earth apart from the rest of the planets. Without water, plants, animals, and people would die. Although water covers approximately 70 percent of Earth's surface, usable water is not as abundant as one might think. About 97 percent of Earth's water is saltwater, resulting in only about 3 percent freshwater on Earth and about 69 percent of the freshwater is locked up in glaciers and icecaps and about 30 percent of Earth's freshwater is stored in groundwater, which leaves less than 1 percent found as easily accessible surface water. Water is of fundamental importance to plants and animals, particularly humans. It is therefore very vital in maintaining life processes and growth (1)

Groundwater is the largest single source of freshwater available for human use. It fills pores or open spaces in soils and rocks, creating aquifers. An aquifer may be a layer of gravel or sand, a layer of sandstone or other rock, or some other material with holes or pores that can store water underground. A soil's texture helps determine how much water the soil can hold, or the soil's water-holding capacity. Based upon the relative proportions of different-sized particles, soil texture can be classified as sand, silt, and clay, with sand being the largest particles and clay the smallest. When soil is a combination of all three textures, it is referred to as a loam, a more complicated soil textural class. (2)

In areas where surface water is not available, Groundwater constitutes significant part of active fresh water resources of the world and is obviously dependable source for all the needs and is most widely distributed precious resource of the Earth. Though the ground water resources are widely distributed, Nature does not provide ground water at the places of our choice**.** The occurrence and distribution of ground water resources are confined to certain geological formations and structures. Groundwater is water that flows or seeps downward and saturates soil or rock, feeding springs and wells; water stored underground in rock crevices and in the pores of geologic materials that make up Earth's crust.

The sandy soil has larger pores and a low water-holding capacity, allowing water to drain more quickly than clay and silt soils. Since a soil's water-holding capacity is a measure of how much water might be stored for plants or human use. A soil's porosity describes the amount of open space, or pores, in the soil. A soil's permeability measures how water flows through the soil. The porosity and permeability of the soil, coupled with gravity, affects how much water is stored as groundwater. Water is the only chemical compound naturally found on Earth's surface in all three physical states as a solid, liquid, and gas. Liquid water is called the "universal solvent," as it can dissolve more materials than any other liquid. Liquid water, like rain, dissolves some carbon dioxide and other gases as it falls through the atmosphere. Although people may think rainwater is fresh water, carbon dioxide mixed with water sometimes creates a mild carbonic acid. (3)

In groundwater explorations geophysical methods are mostly directed to study the hydro-geologically active zone (zone of groundwater circulation), The study of the earth using quantitative physical methods, remote insight into the earth in order to identify/delineate structurally weak zones (like faults, fracture zones and fissures) that usually serve as conduits for the groundwater to flow into or out of the aquifers , mapping the depth and morphology of impermeable beds and outline their regional trends, delineating the interfaces between fresh and saline water and also approximately evaluate degree of mineralization of underground water, acquiring information related with contaminations of subsurface water, study of groundwater dynamic (velocity and direction of groundwater flow/movement). (4)

Geophysical methods comprise of measurement of signals from natural or induced phenomena of physical properties of sub surface formation. Various physical properties that are made use of in different geophysical techniques are electrical conductivity, magnetic susceptibility, density, elasticity & radioactivity. Electrical methods of prospecting include a large group of geophysical techniques employed for investigating the electrical fields of the earth. Such fields are generated in the earth naturally or artificially by generators or batteries. The distribution & intensity of electrical fields depend on the source of excitation as well as upon the electrical properties & geological structures in the region. The different electrical properties that influence electrical fields are primarily the resistivity ρ, the dielectric permeability C & magnetic permeability ε. Electrical parameters vary depending upon the lithology & more influenced by the presence, content & quality of water. (5)

Geophysical methods make use of the interaction of electrical & magnetic fields with each other & their mutual interaction with matter to determine the properties of electrical conductivity or magnetic permeability of the earth. Magnetic method based on the measurement of susceptibility contrast between the anomalous body & the rock around it. Ferromagnetic minerals particularly magnetite are the main source of local magnetic anomalies. (6)

During the past two decades a growing number of investigators have given their attention to the application of geophysics to some of these problems (7) But it is only recently that these studies have found a quantitative basis in the determination of porosity and permeability

1.2 Overview of ground water system; process, model and geology

Ground water regions have been subdivided into hydrogeological settings. Hydrogeological setting is defined as a composite description of all the major geological and hydrological factors that affect and control ground water movement into, through and out of an area. An aquifer is a water-bearing geological formation, group of formations, or part of a formation that contains sufficient saturated permeable material to yield usable quantities of water to a well or springs. Within each aquifer, ground water moves from areas of recharge to areas of discharge. Flow direction, velocity, and discharge rates are controlled by aquifer porosity, hydraulic conductivity, and hydraulic gradient. Aquifers range in area from a few to hundreds of square miles. (8)

Aquifer zones are subdivisions of aquifers with differing hydrological conditions. Aquifer zones include recharge and discharge areas as well as confined and unconfined areas. Ground water occurs in openings in the rocks that form the Earth's crust. The volume of the openings and the other water-bearing characteristics of the rocks depend on the mineral composition, age, and structure of the rocks. (9)

Earth materials that primarily act as barriers to ground water flow include silt, clay, shale, glacial till, and unfractured crystalline rocks. The portion of infiltrating water that percolates to the water table is termed recharge. The amount of recharge by precipitation depends on factors such as the amount of rainfall soil type, subsurface geology, slope, aspect, depth to the water table, and vegetation cover. At present, our ability to quantify recharge and discharge is limited, and no uniformly acceptable methods exist for measuring recharge and discharge fluxes

The one common factor for all ground water systems, however, is that the total amount of water entering, leaving, and being stored in the system must be conserved. An accounting of all the inflows, outflows, and changes in storage is called a water budget. General methods of practice have been produced for geophysical techniques in groundwater exploration (10)

1.3 Ground water studies in Ethiopia

The occurrence of groundwater is mainly influenced by the geology, geomorphology, tectonics and climate of the country. The variability of these factors in Ethiopia strongly influences the quantity and quality of the groundwater in different parts of the country. The geology of the country provides usable groundwater and provides good transmission of rainfall to recharge aquifers, which produce springs and feed perennial rivers. (11)

In Ethiopia, there are a number of lithological units of varying age and composition including metamorphic, sedimentary and igneous rocks. In many parts of the country, groundwater is an important source of potable water. This is especially true for rural areas as well as for towns. However, the occurrence of groundwater is not uniform because it depends on various environmental and geological factors (12)

The difficulty of obtaining productive aquifers is peculiar feature of Ethiopia, which is characterized by wide heterogeneity of geology, topography, and environmental condition. The understanding of the thickness of the aquifer helps to evaluate the resource and the reserve of water and the depth of drilling. The investigation of the factors that regulate the outflow of the ground water is important to define the circulation of water within the aquifer. (13)

1.4 Reviews of previous studies

A lot of geophysical investigations have been carried out in different parts of the world for groundwater investigation: (14) Modern geophysical methods for subsurface water exploration: Geophysics, v. 28/4, p. 634-635 cited the effectiveness of the electrical resistivity method in the investigation for groundwater in complex granite areas. The method is used to map fractures, gorges gouge, and faults which act as water reservoirs. (15)

For groundwater investigations, the most significant parameters that have been used for describing an aquifer system are ones that relate to the porosity and permeability of the aquifer and surrounding. Electrical conductivity, or its inverse resistivity, is the proportionality factor relating the electrical current that flows in a medium to the applied electric filed. It is the ability of an electrical charge to move through a material. It has been correlated with porosity through the work of (16)

A relationship often exists between electrical conductivity and the clay content or fluid type. Groundwater flow along two structurally distinct transects from the western Rift escarpments to the Rift floor and suggested that Rift floor aquifers are fed by a deep groundwater flow from the escarpment to the Rift, mainly along transverse faults connecting Addis Ababa to the Rift floor. However, the occurrence and direction of multiple flow paths from the escarpment to the Rift floor (i.e. beyond a transect approach) as well as the further direction of the groundwater flow system in the Rift floor aquifers is not yet well understood.

(17)

1.5 Problem of statement

Groundwater is renewable, finite and essentially a dynamic resource that is recharged by various sources. The most important mode of recharge to the aquifer is the direct infiltration of rainwater governed by several natural factors, which varies according to climate, topography, soil and sub-surface geological characteristics. The stored capacity of groundwater reservoirs combined with small flow rates provides a large, extensive distribution of water supply. Two geophysical methods (VES and Magnetic) methods and methodologies were employed in order to:

- Acquire qualitative characteristics about geological features, including water-bearing formations, and perform quantitative analysis (i.e. estimate their thickness, lateral extensions and physical properties: electrical resistivity/conductivity and magnetic susceptibility).
- To identify/delineate structurally weak zones (like faults, fracture zones and fissures) that usually serve as conduits for the groundwater to flow into or out of the aquifers.
- Approximately evaluate degree of mineralization of underground water.
- Study of groundwater dynamic (velocity and direction of groundwater flow/movement).

1.6 Location and geological setting of the study area

The study area is located in about 25 km from Addis Ababa in the east direction on the upper north-western narrow part of the Awash basin, situated in central Ethiopia, in Oromia Regional State. Legedadi area is one of the main water supply sources of Addis Ababa city. The region is characterized by a range of volcanic mountains rising to elevations range from 2,293.7m.a.s.l to 3,211m.a.m.s.l. Mountains, hills, gullies, steep to undulating foot-slopes, valleys, dissected side slopes of mountains, and undulating plains and flat to almost flat plains are the major physiographic units found in the catchment area.

The study area is located within 491157E – 495706E and 997939N – 1009961N with increase in elevation towards the north direction. Eucalyptus, grass and natural vegetation, built-up areas (paved road, dam, concrete buildings in Sendafa town, and water bodies), bare soil, moderately cultivated land and shrub-land are the main units of the catchment area.

1.7 Objective of the study

A geophysical study was carried out around Addis Ababa. Vertical Electrical sounding, magnetic survey methods were employed mainly focuses on the evaluation of the groundwater potential. This thesis work has both general and specific objectives which are outlined as follows.

1.7.1 General objective

The main objective of the research is to conduct geophysical investigation to identify the potential area for groundwater and indicate the most promising sites of waterways for drilling capable of supplying potable water on continuous basis.

1.7.2 Specific objective

The research work is carried out to have an insight into the subsurface geology of the study area with the following specific objectives in order to:

- Detect subsurface layers, their thicknesses, and their resistivity.
- Investigate the hydrological conditions of the area with the view of delineating the potential area for groundwater development.
- Model geological structures e.g. fault and fractures, which are conductive bodies, thus may accommodate groundwater.
- Locate possible and suitable site for productive boreholes in the study area, and
- To determine the depth to the productive ground water.

1.8 Thesis Layout

The total work of this thesis is organized into six chapters. Chapter one of the thesis describes the introduction part which include study area description, statement of the problem, objective, methodology and instrumentation and previous work. The second chapter incorporates geology; chapter three is Geophysical methods employed in the investigation. Chapter four covers the data acquisition and processing and data presentation. The interpretation of the different results and discussion is included in chapter five. The last chapter includes the conclusion and recommendation of the overall work of the thesis.

CHAPTER-2

2 GEOLOGY OF THE STUDY AREA

Weathering and tectonics govern the hydro geochemical characteristics of earth materials. The flow, origin, and chemical constituent of groundwater are controlled by the type of lithology, distribution, thickness and structure of hydrogeological units through which it moves. The study area comprises volcanic rocks mainly rhyolites, basalts, trachyte's, starchy-basalts, coria, welded and unwelded tuffs are the dominant rock outcrops. Unconsolidated materials of different origin are also occurred in the study area. These rocks are the major groundwater supply for large parts of Addis Ababa.

Geomorphologic setup of the area can be deduced based on previous work conducted in the area, lithological log obtained from boreholes and data collected during the fieldwork. Groundwater dynamics and regional flow patterns in active rifts such as the East African Rift, Dead Sea Rift or Rio Grande Rift are, to a large extent, controlled by the structural setting

The study area is characterized by alternate eruption of acidic and basic lava flows from different centers. In between successive lava flows physical disintegration and chemical decomposition of rocks exposed at the surface; subsequent erosion and deposition; and tectonic activity taken place that has modified significantly the geomorphologic set up of the area. The main porosity groups identified are fracture porosity and interstitial porosity. (12)

2.1 General geology

The older volcanic rocks mainly comprising ignimbrites, trachyte, tuff and ash flows as well as older basalts are characterized by low to moderate permeability and productivity aquifers are expected generally to occur in the northern and north eastern parts of Addis in the surroundings of Legeadi.

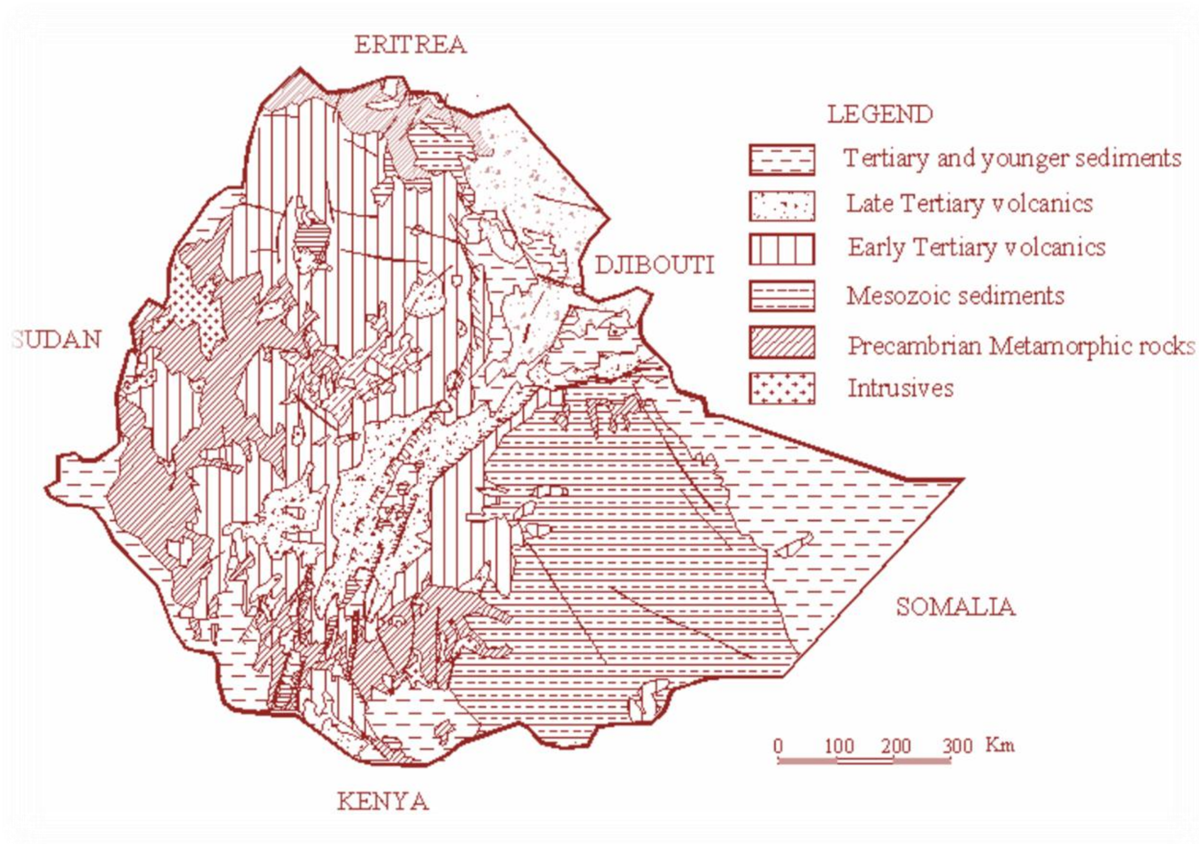


Figure 2.1 modified geological map of Ethiopia

2.2 Local geology

The Addis Ababa area is made up of Oligocene-Miocene and Quaternary volcanic rocks. The rock chemistry ranges from basic to acidic. The northern part of the city is made of rhyolites and trachyte of older age than the basaltic rocks of the southern sector. The main volcanic centers are Entoto, Yerer, Furi and Wachacha.

2.2.1 Geologic map

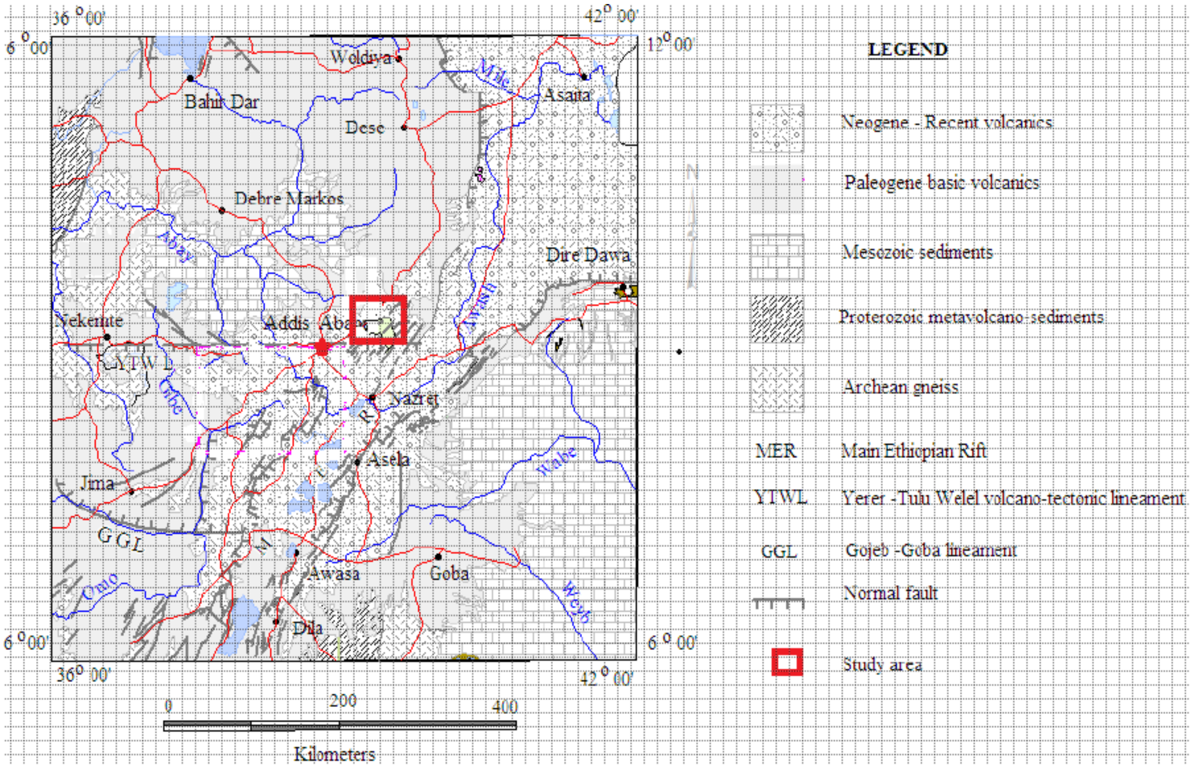


Figure 2.2Simplified geological map of central Ethiopia (Modified after Tefera et al., 1996).

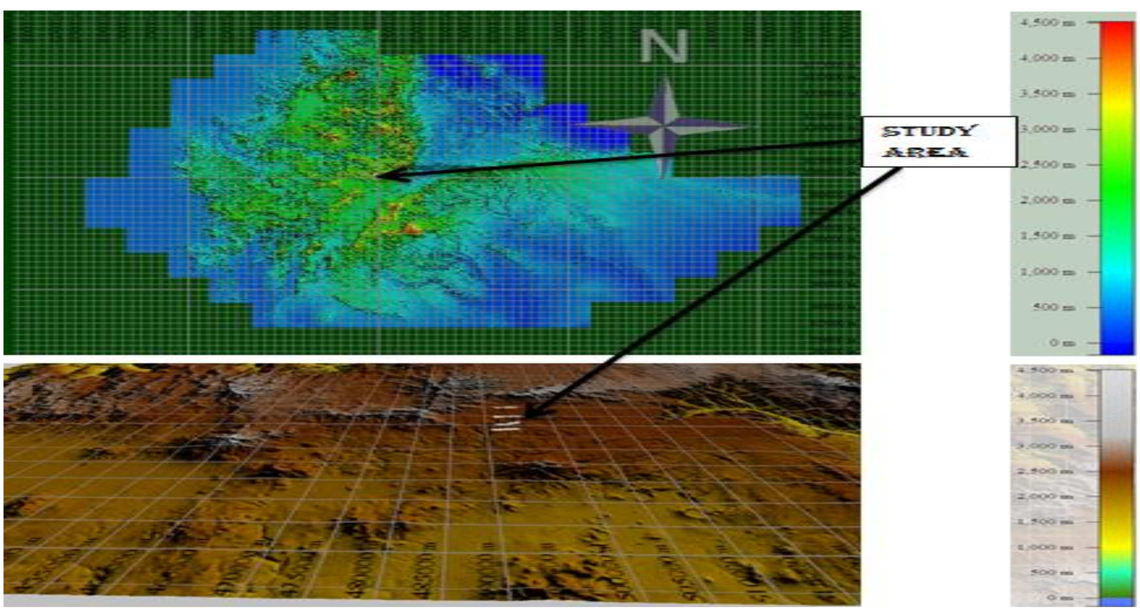


Figure 2.3 Location map of the study area from the Global mapper view

2.2.2 Geologic section

The geologic section of Legedadi area comprises of Acidic volcanic rocks about 150 m thickness, Quaternary and tertiary Basalts with thickness about 60 m below the acidic volcanic rocks, again acidic volcanic rocks about 200m thick above the scoreseous basalts found below 320m depth.

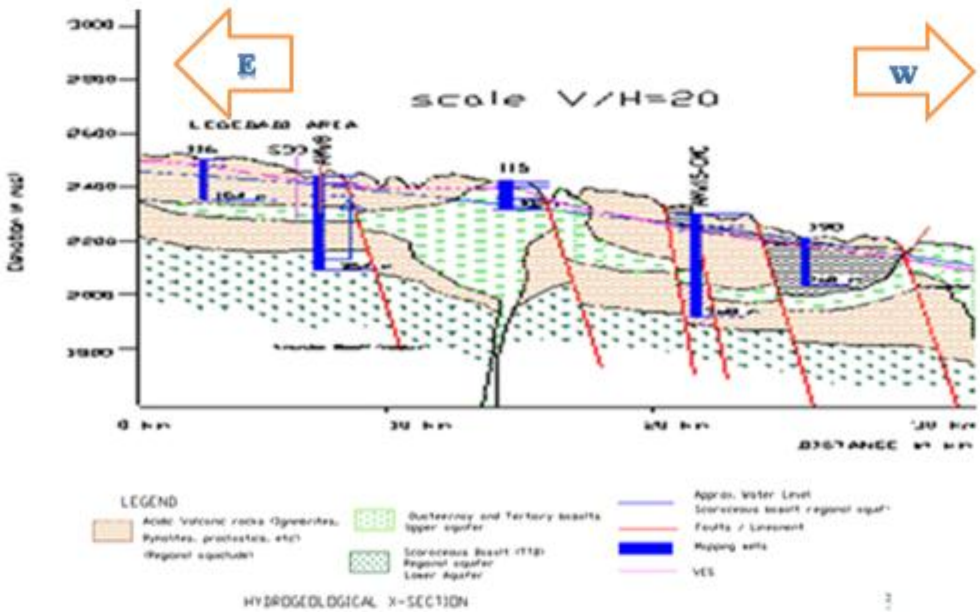


Figure 2.4 modified Hydrogeological cross-section of legedadi area

CHAPTER 3

3 GEOPHYSICAL METHODS USED OVER THE AREA

Theory of geophysical methods

The essence of geophysical methods is to analyze the real picture of the subsurface geology of a particular area of interest. Devices used for these methods locate discontinuities caused by contrast in physical properties of the rocks. However, due to the complexity of the geophysical pattern and signature of these discontinuities in geophysical interpretations, an integrated survey or the correlation of two or more geophysical methods are used so as to reveal the subsurface geology of the area of interest. In this project, an integrated geophysical survey was adopted which comprises of magnetic survey and vertical electrical sounding methods.

Both Magnetic and Resistivity Survey methods of the geophysics sciences were applied in this groundwater investigation. Total of sixteen (16) Vertical Electrical Soundings (VES) and four (4) magnetic profiles were probed in the area under investigations. Geophysical surveys are essential for interpretation of variation in measured response at the surface to certain forces, either natural or artificially generated within the earth's crust. Such variation result from differences in physical characteristics such as density, elasticity, magnetism, and electrical resistivity of the underlying layers.

The resistivity of the ground is measured by sending current into the ground at the current electrodes and the corresponding potential difference is measured at the potential electrodes, which is then converted to apparent resistivity value by multiplying with an appropriate geometrical factor. Different factors affect the resistivity in the subsurface (18)

Electrical resistivity of subsurface structures changes significantly in the presence of groundwater. Over homogeneous half-space current flow in subsurface will decrease with the increase of current electrode separation at the same applied voltage (19)

An increase in normalized current flow at a particular current electrode separation reveals the presence of a conducting body in the path of the current flow. Further, a similar amount of current flow observed with an increase of current electrode spacing also indicates the presence of conducting features in the subsurface. For a homogeneous isotropic media (earth with constant resistivity) the following laws apply:

Kirchhoff's law: Law of conservation of electric charge and its continuity:-

div j=0, ……………………………………………………………….(1)

Where j – is current density

The total electric charge in an isolated system, i.e., the algebraic sum of the (+) and (-) charges present at any time, never changes, unless there is a source or leak in the system. Quantity of electric current going in to voluminous material must leave the other side unless there is a source or leak.

Ohm's law: In a differential form this law is stated as:

j=σ E ……………………………………………………………………(2)

, Where Current density j is directly proportional to the electric field strength (E) and conductivity (σ) but inversely proportional to the resistivity (ρ) of the medium.

Potential function (U) is related to the Electric field strength (E) as

E= - grad U ……………………………………………………………… (3)

U must satisfy two conditions: Potential at large (infinite) distance from the source must converge to zero. Potential field should be continuous across the boundary between two media with different resistivity. If it were not true, there would be a finite difference in potential over a short distance across the boundary, which would correspond to an infinite potential gradient. According to Ohm's law, this would result in an infinitely large amount of current density, which is not possible.

$U_1 = U_2$ ………………………………………..……… (4)

$$\sigma_1 \frac{\partial U_1}{\partial n} = \sigma_2 \frac{\partial U_2}{\partial n} \quad \text{.......................................} \quad (5)$$

σ_1 and σ_2 – electrical conductivity of the contacting media and $\partial U_1/\partial n$ & $\partial U_2/\partial n$ – normal potential component;

The normal components of the current flow through the boundary of two media have to be the same. This condition is a consequence of the requirement that current is conserved. "All the current entering the boundary plane from one side must leave it from the other side".

Laplace equation: Obtained by combining Ohm's law and divergence condition, i.e., j=σE &

E = - grad U or eq (2) and eq (3).

$$j = \frac{1}{\rho} E = -\frac{1}{\rho}(-gradU) \quad \text{.......................................} \quad (6)$$

$$j = \frac{1}{\rho} gradU \quad \text{.......................................} \quad (7)$$

From eq (1) $Div\, j = 0$

So , $\frac{1}{\rho} gradU = 0$ .... (8)

=> $grad \frac{1}{\rho} gradU + \frac{1}{\rho} Div\ gradU = 0$ .... (9)

$$Div\ grad\ U = \Delta U = 0 \quad \text{.......................................} \quad (10)$$

=> $\nabla^2 U = 0,$ .... (11)

fundamental equation in DC electrical prospecting.

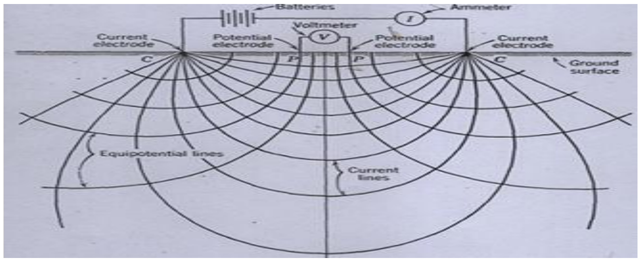


Figure 3.1 Electrical circuit for resistivity determination and electrical field for a homogeneous subsurface stratum, Adopted from hydrogeology and ground water lecture note

$$E = \frac{\rho I}{2\pi r^2}\ , \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

This is the expression for electric field strength for homogeneous area.

The resistivity is determined using observed ΔU (or electrical field strength (E) created by current flow (I). These relations are expressed by Ohm's Law and potential function:

$j = \sigma E$, j – current density,

$$j = \frac{I}{2\pi r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (13)$$

$E = \frac{j}{\sigma} = j\rho$ and $E = -gradU$

Where, $\frac{1}{\sigma} = \rho$

$$j = \sigma E = -\frac{1}{\rho}\frac{dU}{dr} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (14)$$

Considering a homogeneous semi-spherical media;

$$j = \frac{I}{A} = \frac{I}{2\pi r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The electric potential is;

$$E = j\rho = -\frac{dU}{dr} = -\frac{\rho I}{2\pi r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (16)$$

$$dU = \rho I \frac{dr}{2\pi r^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (17)$$

The potential field at point M is,

$$U = \int dU = \frac{\rho I}{2\pi}\int_r^0 \frac{\partial r}{r^2} = \frac{\rho I}{2\pi r} + c$$ ……………………………………(18)

I=0 when r→∝; therefore, it is necessary to accept C=0. If so,

$$U_M = \frac{\rho I}{2\pi r}$$ ……………………………………………………… (19)

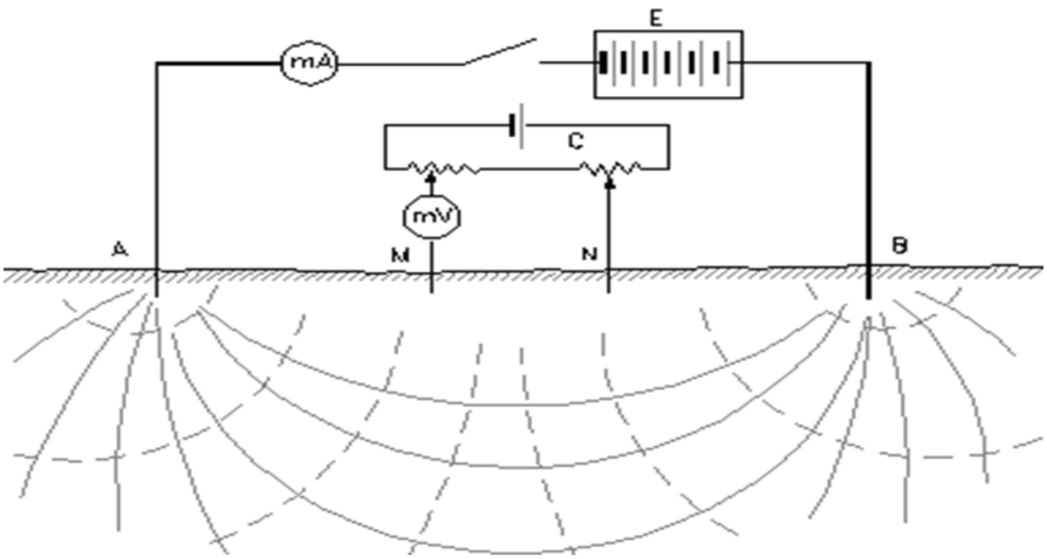


Figure 3.1 Adopted from hydrogeology and ground water lecture note

The potential at points *M* and *N* located at distances $r_1 = r_{AM}$ & $r_2 = r_{AN}$ from source electrode *A* is determined as:

$$U_N = \frac{\rho I}{2\pi}\frac{1}{AN}$$ ……………………………………………………… (20)

$$U_M = \frac{\rho I}{2\pi}\frac{1}{AM}$$ …………………………………………………….. (21)

$$\Delta U = U_M - U_N = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{AN}\right)$$ …………………………………… (22

Potential due a dipole source

$$U_{AM} = \frac{\rho I}{2\pi x}$$ - Potential at M due to A

$$U_{BM} = \frac{\rho I}{2\pi}\frac{1}{l-x}$$ - Potential at N due to A

Now the potential at M due to A & B is;

$$U_M = U_{AM} - U_{BM} = \frac{\rho I}{2\pi}\left(\frac{1}{x} - \frac{1}{l-x}\right), \quad (23)$$

the potential difference between A and B will be;

$$\Delta U = U_M - U_N = \frac{\rho I}{2\pi}\left(\frac{1}{AM} - \frac{1}{AN} - \frac{1}{BM} + \frac{1}{BN}\right) \quad (24)$$

And the apparent resistivity is calculated by;

$$\rho = \left\{\frac{\Delta V}{I}\left(\frac{2\pi}{\frac{1}{AM}-\frac{1}{AN}-\frac{1}{BM}+\frac{1}{BN}}\right)\right\} \quad (25)$$

$$k = \left(\frac{2\pi}{\frac{1}{AM}-\frac{1}{AN}-\frac{1}{BM}+\frac{1}{BN}}\right),$$

K is array coefficient or geometric factor.

Now the apparent resistivity is,

$$\rho_a = \frac{K\Delta U_{MN}}{I} \quad (26)$$

ρ_a physically characterizes the degree of distribution of current lines close to the receiving electrodes or in-homogeneity of the ground and it depends on the geometry of the array. The basic principle behind electrical methods is that because different geologic materials have different electrical properties, layers in the subsurface can be identified on the basis of these properties.

The magnetic method of geophysical exploration involves measurements of the direction, gradient, or intensity of the Earth's magnetic field and interpretation of variations in these quantities over the area of investigation. The magnetic field around the Earth, geomagnetic field, is believed to be mainly originated from the liquid outer core of the Earth containing high concentration of iron. Structures can be detected by measuring local variations of the geomagnetic field.

The intensity of the magnetic field on or above the surface of the Earth is dependent upon the location of the observation point in the primary magnetic field of the Earth and local or regional concentrations of magnetic material. The intensity of the Earth's undisturbed magnetic field ranges from a minimum of about 26,000 γ at the magnetic equator to more than 69,600 γ near the magnetic poles. The most common use of magnetic data in ground-water studies is to map the depth to the magnetic basement rock. The data interpretation that reflects differences in local abundance of magnetization is especially useful to locate faults and geologic contacts (20)

The magnetic anomalies can be originated from a series of changes in lithology, variations in the magnetized bodies thickness, faulting, pleats and topographical relief. For groundwater resource mapping it is not the groundwater itself that is the target of the geophysics rather it is the geological situation in which the water exists. Magnetic techniques measure the remnant magnetic field associated with a material or the change in the Earth's magnetic field associated with a geologic structure or man-made object. Low magnetic anomalies are observed over fractured formations filled with groundwater in hard rock area (21) and (. (22)If two magnetic poles of strength $m1$ and $m2$ are separated by a distance *r*, a force, *F*, exists between them. If the poles are of the same polarity, the force will push the poles apart, and if they are of opposite polarity, the force is attractive and will draw the poles together. The equation for *F* is the following.

$$F = \frac{m_1 m_2}{4\pi\mu r^2} \quad \text{...}27$$

Where μ is the magnetic permeability of the medium separating the poles; *m1* and $m2$ are pole strengths and *r* the distance between them. Local variations, or anomalies, in the Earth's magnetic field are the result of disturbances caused mostly by variations in concentrations of ferromagnetic material in the vicinity of the magnetometer's sensor. The magnetic field's direction is given by the right-hand rule. Magnetization is a vector quantity which is related with the concept of north and South Pole of a magnet. (23)

3.1 Resistivity of earth materials

The range of resistivity is primarily a function of fluid content and the common target for electrical surveys is the identification of fluid saturated zones. Measured resistivity in Earth materials are primarily controlled by the movement of charged ions in pore fluids. Water is not a good conductor of electricity but ground water contains dissolved compounds that enhance to conduct electricity finally porosity and fluid saturation tend to dominate electrical resistivity measurements. Electrical resistivity of rocks depends upon the electrical resistivity of the mineral grains constituting the rocks' skeleton and the electrical property of solutions filling pore spaces and fractures.

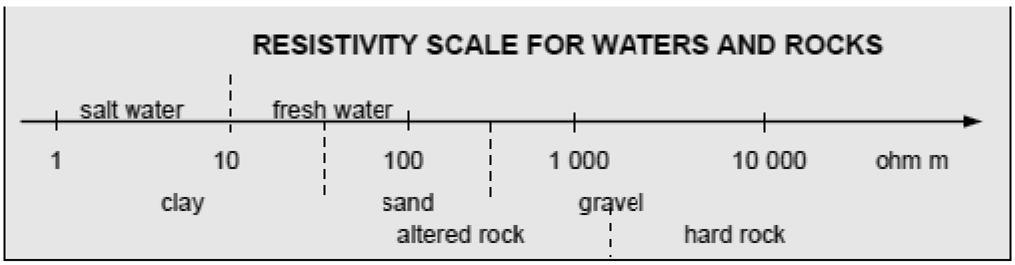


Figure 3.2 Adopted from Introduction to Geological prospecting, 1998 Durbin, M.B.

Resistivity of water-bearing rocks decreases with increasing water contained in pores. Pores must be interconnected and filled with water in order that the rocks can conduct electricity. When the rocks are fully saturated with water, resistivity varies approximately as the inverse square of the porosity and relation between resistivity and porosity is explained by Archie's law as:

$$\rho = a\rho_w p^{-m} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 28$$

p – is a parameter of porosity (it mainly depends upon the porosity and structure of pore spaces), ρ - is the bulk resistivity of rock, and ρw - resistivity of the water contained in pore structure .

And the Archie formula for non-clayey formations is

$$Rock\ resistivity\ =\ F\ x\ Water\ resistivity \quad \ldots\ldots\ldots\ldots 29$$

F = Formation Factor = a / (porosity) N

Resistivity of fractured rocks depends on the type and amount of solutions filling pore spaces and the degree of fracturing. Fractured rocks have lower resistivity than their undisturbed equivalents. Electrical resistivity of the earth decreases with the increasing of temperature. Intensity of resistivity can also be highly affected by weathering activities. Highly weathered and fractured rocks below the water table may have resistivity about 10 times lower than their compacted and fresh equivalents. Forms, sizes and arrangements of pores as well as minerals grains in rocks play great role in determining the flow of electric current and with the increasing of moisture content electrical resistivity decreases. The electrical resistivity and temperature are related in:

$$\rho_t = \frac{\rho_{18}}{1+\rho_t(t-18℃)} \qquad \text{……………………………………………………}30$$

Resistivity of typical rocks and sediments may vary from approximately 1 Ohm-m to over 10,000 Ohm-m, at least 4 orders of magnitude. Sedimentary rocks generally exhibit resistivity ranging from 10–1000 Ohm-m (24), depending on the degree of saturation, pore fluid resistivity and % clay. Clay tends to reduce resistivity due to conductive pathways along the surface of negatively charged clay particles. Igneous and metamorphic rocks generally exhibit higher resistivity, usually in the 500–10,000 Ohm-m range. These high resistivity values are mainly due to lack of porosity and lack of clay. (24)

Resistivity value of common rocks

Type of Rock	Resistivity value (ohm-m)
Sea Water	0.2
Clay	1–100
Topsoil	50–100
Ground Water	0.5 – 300
Graphitic schist	10–500
Gravel	100–600
Sand	1 - 1,000
Weathered bedrock	100–1000
Sandstone	200–8000
Loose sand	500–5000
Limestone	500–10 000
Basalt	200–100 000
Greenstone	500–200 000
Gabbro	100–500 000
Slates	500–500 000
Quartzite	500–800 000
Quartz	4×10^{10} - 2×10^{14}
Air	Infinite

Table 3-1 Resistivity valu of common rocks

Current is injected into the earth through a pair of current electrodes, and the potential difference is measured between a pair of potential electrodes during resistivity surveys. The potential and current electrode arrangement is variable and linear.

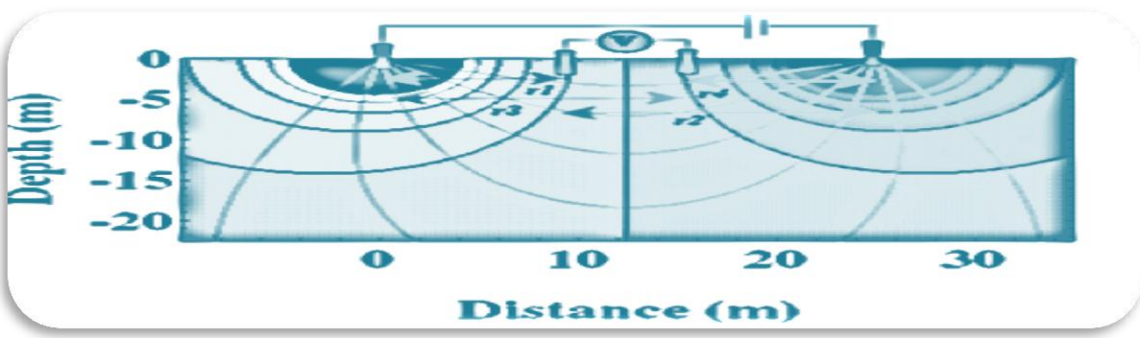


Figure 3.3 Modified but Adopted from Applied and Environmental Geophysics, 1999, Sharma,V.,P

3.2 Vertical Electrical soundings (VES)

Electrical sounding (vertical electrical profiling or electrical drilling) is a process by which depth investigations are made through successive resistivity measurements done with regularly increasing electrode separations, while the center of the configuration and its orientation are remaining fixed. The magnitude of apparent resistivity values measured using this method depends upon the peculiarities of the geological sections under investigation, i.e., layers resistivity and thickness ration; and types of arrays (electrode configurations) used and their sizes. The resistivity survey method applied the Schlumberger's Electrodes Configuration array with maximum current electrode spacing AB/2 at maximum length of 1500m with maximum corresponding potential electrode spacing MN/2 of 90m

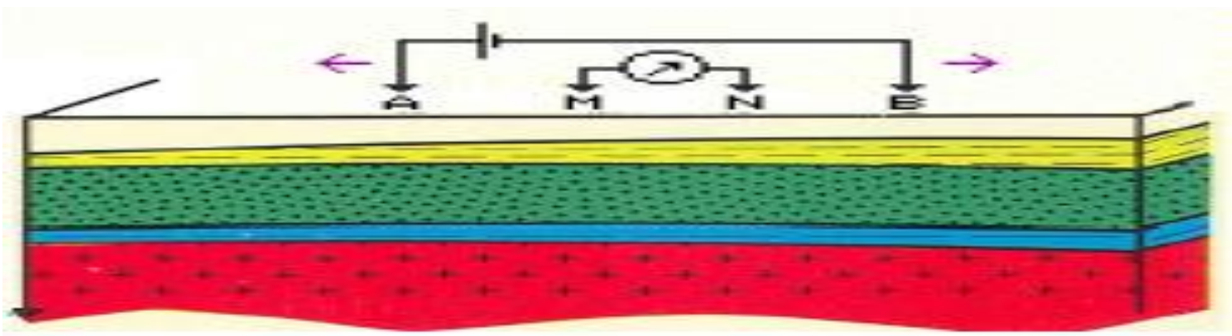


Figure 3.4 Modified but Adopted from Society of Exploration Geophysicists

The resistance values read from the resistivity meter were multiplied with their respective constants (K) to obtained apparent resistivity values.

$$Resistivity\ (ohm.m) = Rho = K_x V_{MN} / I_{AB} \quad \text{.................................. 31}$$

0The apparent resistivity values obtained were plotted against the corresponding current electrode separation distance AB/2. Four (4) electrodes are attached to the ground and an electrical current is applied between two of them. By measuring the potential difference between the two other electrodes the electrical resistivity can be determined. VES has been successfully applied for saltwater intrusion (25)

The large variations in the electrical resistivity values of different rocks and minerals make the Electrical resistivity method very useful. Electrical resistivity method can be used in groundwater exploration to delineate aquifers. By increasing electrode spacing's, multiple Vertical Electrical Sounding measurements are carried out at the same location, resulting increasing depth of penetration. The objective of Electrical Sounding VES is to deduce the variation of resistivity with depth below a given point on the ground surface and to correlate it with the available geological information in order to infer the depths and resistivity of the layers present. In VES, with Schlumberger, the potential electrodes are moved only occasionally, and current electrodes are systematically moved outwards in steps AB > 5 MN. (26)

3.2.1 Measurement procedure and field survey method of vertical electrical sounding

In legedadi vertical electrical sounding /VES/ survey was carried out along the transect lines T1-T4 every one kilometer. In order to get the maximum depth of investigation AB/2 = 1500m or current electrode spacing 1500m Schlumberger array was used for all the four transects. The operational procedure of VES survey in field was;

1. Laying of sounding traverse as per the selected configuration, parallel to the general strike of the geological formation.
2. Arranging of current electrodes at their selected position.
3. Connection of current electrodes C1, C2 through cables.
4. Checking of ground resistance in the transmitter through C1 and C2 to select the input voltage range.
6. Send current through C1 and C2, measure the current (I) and record
7. Nullify the self-potentials of the ground and measure the potential difference (V) in the receiver and record.
8. By taking the current and potential difference, calculate the resistivity using geometrical factor of the configuration.
9. Move the current electrodes to the next position and record current and voltage, calculate resistivity.
10. The procedure repeated until the last observation of the sounding.
11. The data so obtained is plotted on log-log sheet for apparent resistivity versus half current electrode separation.

12. Interpretation of the field curve using partial curve matching and with software's.

The VES observation points were generally located at an interval of 1kilometer, however at places these positions were shifted up to 100m in line and sometimes off the transect lines to find suitable measurement ground.

3.2.2 Electrode configuration

This is determined by the mode of arrays of the potential and current electrodes. There are different types of electrode arrangements that can be used in the resistivity method. These include the Square, Dipole-Dipole, Schlumberger, Pole-Dipole, Wenner, LeePartition, Gradient, Pole-Pole, Crossed Square array, Pole-Pole, and others. Lee Partition electrode array In general two current and two potential electrodes are used in electrical resistivity surveys except Lee Partition electrode array which uses five electrodes. For this survey, the Schlumberger array method was employed.

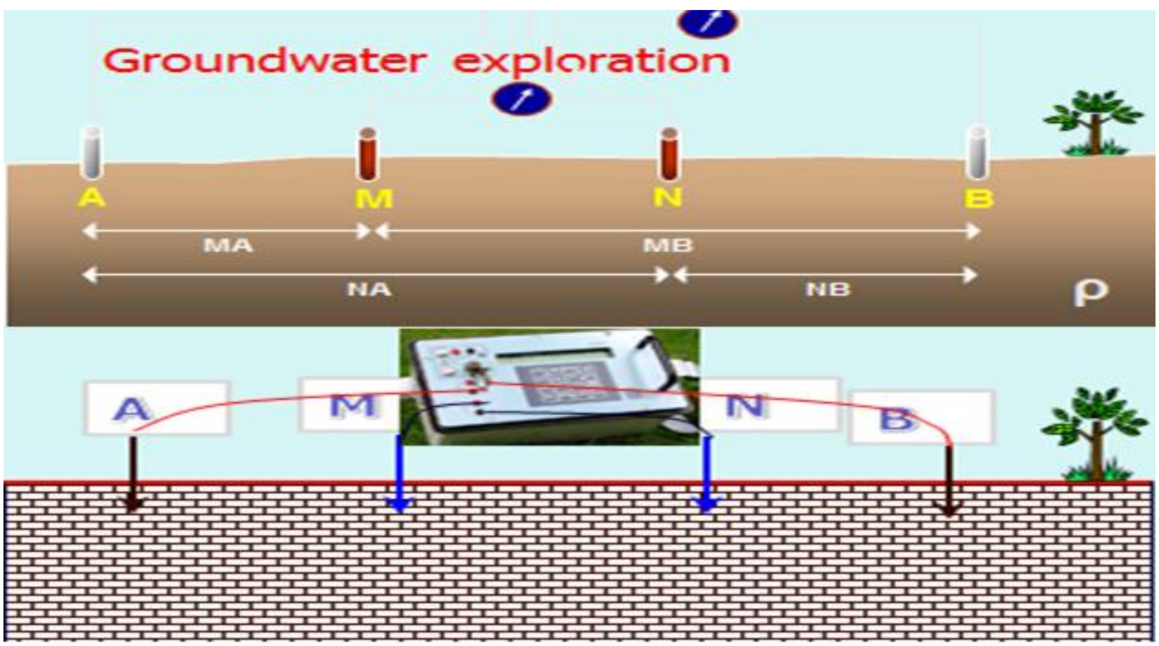
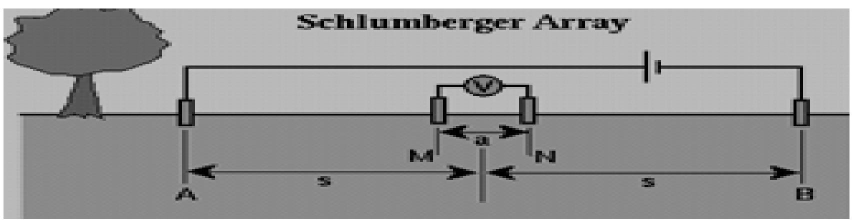


Figure 3.5 Modified and adopted from Dr. Bakhitar Q.Aziz Electrical Method Lecture note

3.2.2.1 Schlumberger Electrode Arrangement

This is a collinear array of electrodes in which the potential electrodes are located within the current electrodes. This electrode array is symmetrical because the station of measurement is at the center of the array. Schlumberger electrode configuration has a high vertical resolution,

The maximum depth of investigation of Schlumberger configuration for Vertical Electrical Soundings is 0.125 AB. (27) The maximum depth of information is about 0.125 AB Schlumberger array is the most widely used in the electrical prospecting. Four electrodes are placed along a straight line in the same order AMNB, but with AB ≥ 5 MN and is less sensitive to lateral variations and faster to use as only the current electrodes are moved. (28)



$$\rho_a = \left[\frac{\left(\frac{AB}{2}\right)^2 - \left(\frac{MN}{2}\right)^2}{MN}\right] \times \pi \times \frac{V}{I} \quad \ldots\ldots 32$$

3.3 Magnetic field of the earth and Magnetic susceptibility

The earth's magnetic field is thought to be caused by churning liquid metals in the core which causes electric currents and a magnetic field. The direction of magnetic north and true north are not identical. The geographic North Pole, which is the point through which the earth's rotation axis goes, is about 11.5° away from the direction of the magnetic north pole (which is where a compass will point). However, the magnetic poles shift slightly all the time.

The geomagnetic field at or near the surface of the Earth originates largely from within and around the Earth's core. The geomagnetic field can be described in terms of the declination, D, inclination, I, and the total force vector F. The vertical component of the magnetic intensity of the Earth's magnetic field varies with latitude, from a minimum of around 30,000nT at the magnetic equator to 60,000nT at the magnetic poles. Earth's magnetic field or geomagnetic field is the magnetic field that extends from the Earth's inner core to where it meets the solar wind, a stream of energetic particles emanating from the Sun. The direction of the earth's magnetic field flips direction about once every 200 000 years.

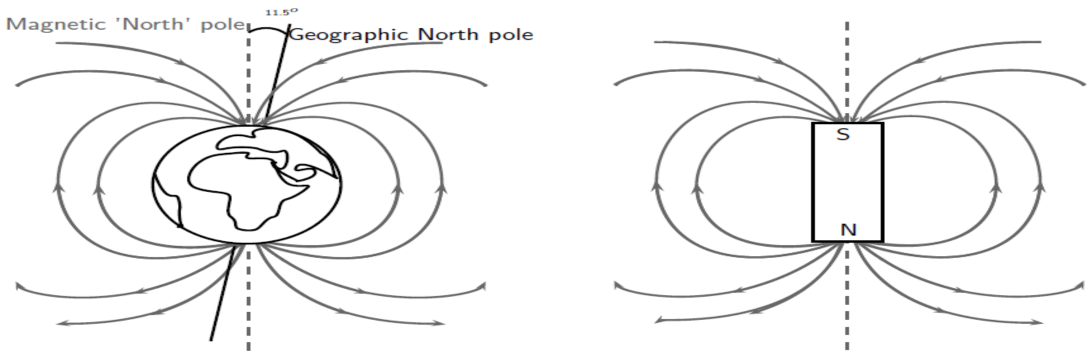


Figure 3.6 Adopted from NASA planetary Geology materials

Magnetic susceptibility is an extremely important property of rocks and to magnetic exploration method. The whole rock susceptibility can vary considerably owing to a number of factors in addition to mineralogical composition such as alignment and shape of the magnetic grains dispersed throughout the rock (24) Weathering generally reduces susceptibility because magnetite is oxidized to hematite.

Soils from volcanic or other igneous rocks have a higher susceptibility than soils weathered from sandstone, limestone or shale. Typical susceptibilities of rocks are given below, but may vary by an order of magnitude or more in most cases:

Material	Susceptibility
Altered ultrabasic rocks	$10^{-4} - 10^{-2}$
Basalt	$10^{-4} - 10^{-3}$
Gabbro	10^{-4}
Granite	10^{-5} -10^{-3}
Andesite	10^{-4}
Rhyolite	$10^{-5} - 10^{-4}$
Shale, Shiest and other,	$10^{-3} - 10^{-4}$
Most Sedimentary rocks	10^{-4} -10^{-s}
Limestone and Chert	10^{-6}-10^{-5}

Table 3-2 Susceptibilities of rocks adopted from (Applications manual for portable magnetometers by S. Breiner geometrics 2190 fortune drive San Jose, California.

A magnetic low is observed over the conducting zones believed to be subsurface fractures. A basic description of their use can be found in (9), describe the use for mapping bedrock topography, and in particular possible groundwater reservoirs in hard-rock (igneous and metamorphic) terrains. Magnetic surveys have also been used to identify basement faulting and other locations of crustal weakness that may represent preferential fluid flow paths. (29)

Rock magnetism is related with the magnetism of the rock forming minerals. Minerals like feldspars and micas are paramagnetic and have higher (positive) susceptibilities ($10^{-4} - 10^{-2}1$). Diamagnetic minerals like quartz and calcite have negative susceptibilities of the order of10^{-5}. The positive susceptibility of ferromagnetic minerals like magnetite (k ~ 1^{-10}) is even larger by some orders of magnitude and in general most important for the magnetization of rocks (30)

3.3.1 Noise and corrections for magnetic variations

The magnetic anomaly is the difference between the Diurnal corrected observed value and the – normal field (IGRF). As it is known that the magnetic field is time varying and the necessary corrections must be applied to get the magnetic anomaly due to various geological sources situated up to the depth where the temperature reaches the Curie point.

The daily variations arising due to the activity of the ionosphere, i.e., the diurnal variations and the normal field which is originating due to convection of conductive liquid core, have to be corrected. While the former one, the diurnal variation, can be corrected by occupying the base repeatedly in course of the magnetic survey, the later one i.e., the normal field is defined and updated world over every 5 years by establishing Geomagnetic observatories and is termed as International Geomagnetic Reference Field (IGRF).

3.4 Instrumentation

3.4.1 Vertical electrical Sounding

The AGI Super Sting R1 electrical resistivity unit having a maximum current output of 2A was used for the Vertical Electrical Sounding (VES) field data collection. This instrument measures and displays the resistance of the subsurface averaged over a number of cycles (two cycles for the purpose of this study). Other instruments used include; metal electrodes, measuring tape, labeled tag (used in locating station position), hammer (used in driving the electrodes into the ground), compass, connecting cables and GPS.

3.4.2 Magnetic survey

The magnetic survey of the total field along all transect lines was carried out using the Geometrics, Inc. G-856AX Portable Proton Precession Magnetometer, which is a versatile rugged tool for such a survey

3.4.3 Global Positioning System (GPS)

VES points and magnetic readings were made with hand held GPS using Adindan system.

3.5 Methodology

In order to achieve the objective of the research**,** the following summarized methodologies were employed. Magnetic and Vertical electrical sounding method of the geophysics sciences were applied in the groundwater investigation in Legedadi area.

The data and information obtained from any sources was interpreted based on the basic knowledge of geophysical methods for data interpretation and the geophysical results were correlating for VES data interpretation, IPI2win+ IP, surfer 10(32-bit), and Win Resist, updated software were used. To interpret the magnetic survey data, Oasis montaj was primarily used. Additional software used in this project is Global mapper, DEM_SRTM, and Mosaic.

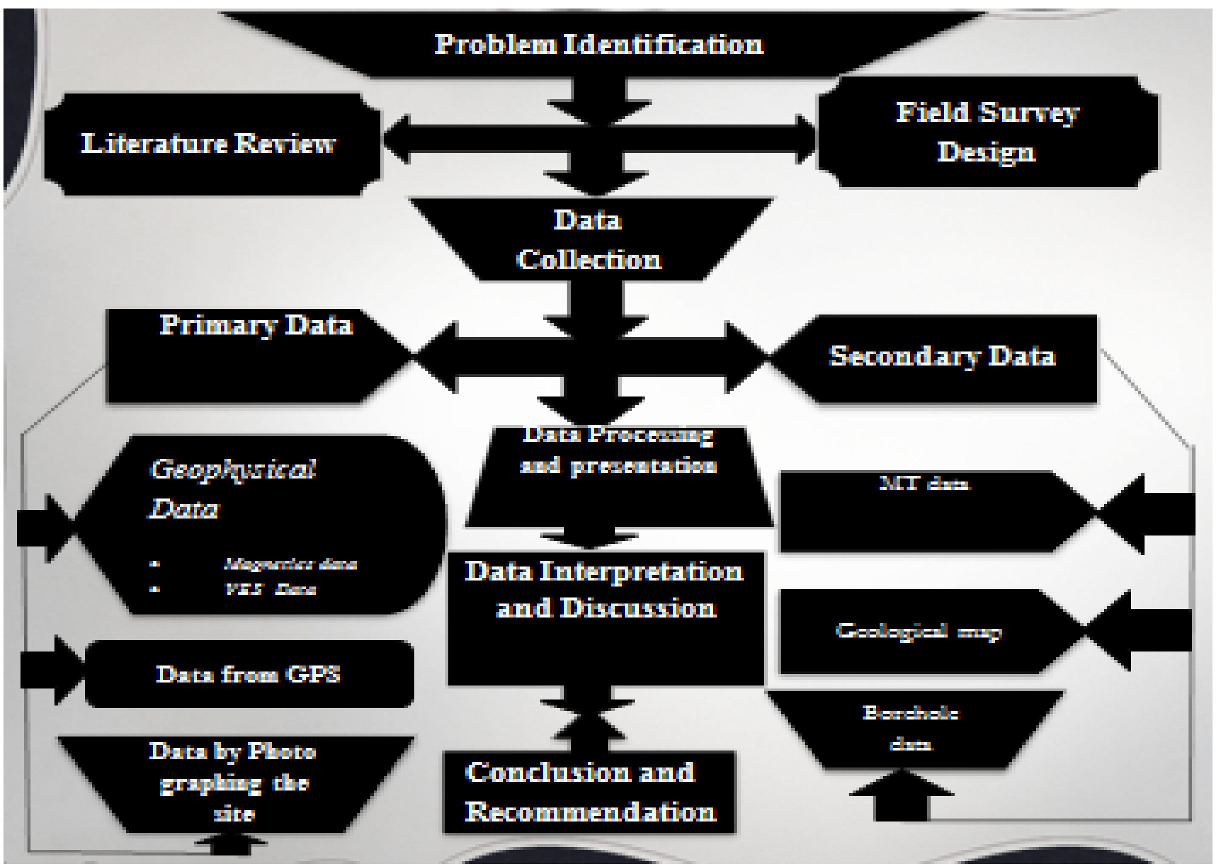


Chart 1 methodology flow chart

CHAPTER 4

4 DATA ACQUISITION AND ANALYSIS

4.1 Data acquisition

4.1.1 Magnetic data

Magnetic data were collected using Proton Precession Magnetometer and geographical coordinates at which the magnetic readings are taken was recorded using Global Positioning System (GPS). Magnetic data was collected along four profiles.

4.1.2 Vertical Electrical Sounding Data

The electrical resistivity survey technique used for this study is the Vertical Electrical Sounding (VES) technique. VES technique measures the vertical variations in ground apparent resistivity with respect to a fixed center of array and employs the collinear arrays. In this method, a series of potential differences were acquired at successively larger electrode spacing while maintaining a fixed central reference point. The induced current passes through progressively deeper layers at greater electrode spacing. Apparent resistivity values calculated from measured potential differences can be interpreted in terms of overburden thickness, water table depth, and the depths and thicknesses of subsurface strata (31)

For this study, the Schlumberger configuration was used to acquire VES data at sixteen (16) sounding points, 4 along each traverse. The electrode separation (AB/2) varied from 1.5 to 1500 m. Current was passed into the ground through the current electrodes, and the resulting potential was measured through the potential electrodes.

4.2 Survey traverse selection

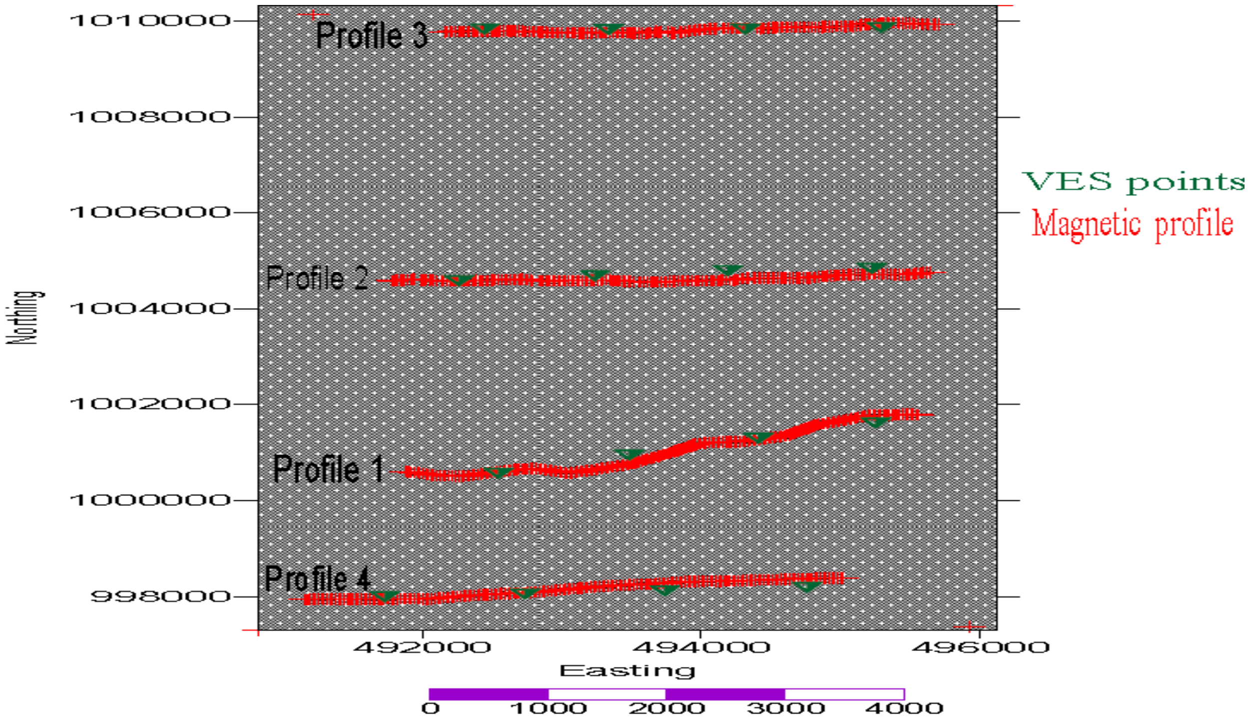
4.2.1 Magnetic survey traverse

The magnetic survey traverse is similar to that of the VES survey. The magnetic survey has 4 profile lines. The magnetic profile lines are directed E-W. On the four profiles a total of 785 magnetic data points was collected. Profile one includes 206 magnetic data points with starting coordinate of 491880 UTME, 1000608 UTMN and elevation of 2427.8m and ending point of 495552 UTME, 1001787 UTMN and 2441.14m elevation. Profile two, which also includes 206 magnetic data points starts from 491785 UTME, 1004590UTMN and at an elevation of 2455.5 meters ends with 495642, 1004758 and 2485.4 m elevation.

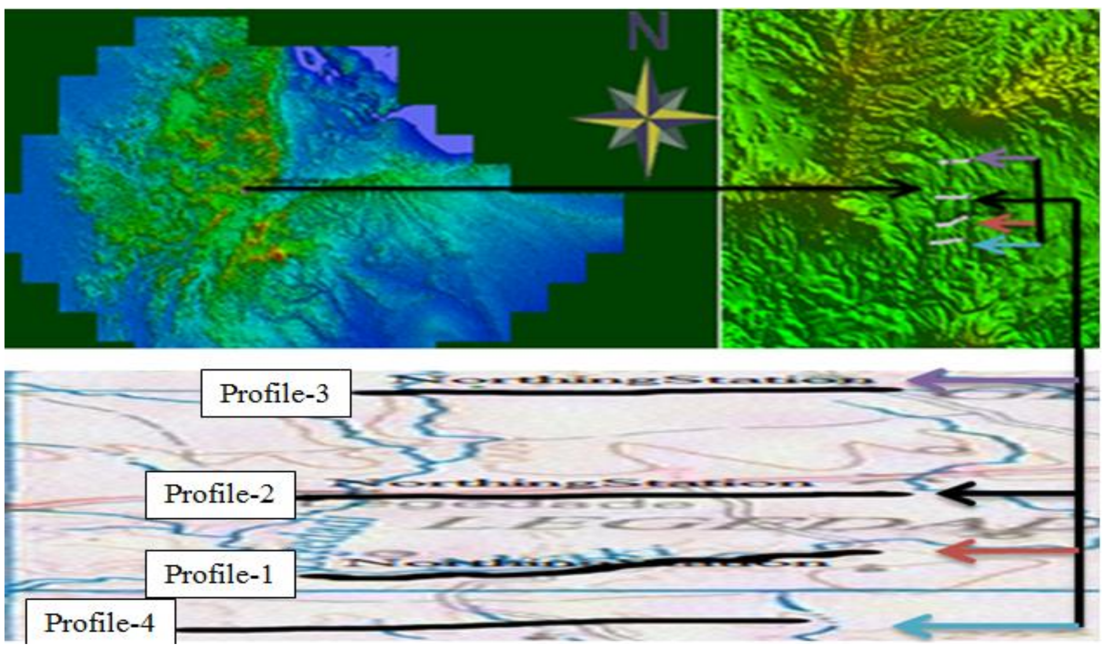
The two remaining profiles, profile three and profile for are also situated starting with 492162 UTME, 1009769 UTMN and 2529.3 m elevation and ends with 495706 UTME, 1009935 UTMN, and 2544.1 m elevation and starting from 491157 UTME, 997939 UTMN, and elevation of 2434.5 and end with 495016UTME, 998386 UTMN, and 2450.9m elevation and also 182 and 192 magnetic data points respectively. Generally a total of the Magnetic data were collected from about 785 data points with average spacing of 20m along the selected profile lines.

4.2.2 VES survey traverse

The Vertical Electrical Sounding survey was also conducted along four traverse lines. VES-1, VES-2, VES-3 And VES-4 are along profile line one with the geographical location starting from 38.9308°E and 9.054° N to 38.96°E and 9.06° N. VES-5, VES-6, VES-7 and VES-8 are also along the profile line two with geographical location from 38.93°E and 9.09° N to 38.96°E and 9.092° N. Profile line three includes VES-9, VES-10, VES-11, and VES-12 and the coordinates are from 38.93°E and 9.14° N to 38.96°E and 9.141° N. The last profile line is line 4 which includes VES-13, VES-14, VES-15 and VES-16 are also from the geographical location of 38.93°E and 9.03° N to 38.953°E and 9.032° N.



1010000
1008000
1006000
1004000
1002000
1000000
998000
Northing
Profile 3
Profile 2
Profile 1
Profile 4
492000
494000
496000
Easting
0
1000
2000
3000
4000
VES points
Magnetic profile



N
Profile-3
Profile-2
Profile-1
Profile-4

4.3 Data processing

4.3.1 Magnetic Data processing

The observed magnetic data on the study area were corrected for diurnal variations. For the purpose of diurnal correction the magnetic data collected at field was recorded in Microsoft excel. Using this software the diurnal variation of each point was calculated based on the reading of the base station and the corrected total field values were then smoothed using a moving average program and the results were plotted at a reasonable scale using Oasis montaj. The most accurate method of geomagnetic correction is the use of the International Geomagnetic Reference Field (IGRF) value. (32)The correction was made using IGRF value of 2005 obtained from Oasis Montaj. Total magnetic field anomaly was obtained by subtracting the diurnal variation and IGRF values of survey data. Finally the magnetic field anomaly was used for processing in order to produce anomaly map, trend map, Analytic map, 3D map and models by using Oasis Montaj of version 6.4.2.The magnetic data processing for profile 1, 2, 3 and 4 is presented in figure 4.1 a-c, figure 4.2 a-c, figure 4.3 a-c, figure 4.4 a-c, figure 4.5 a-d, figure 4.6 a-d, figure 4.7 a-d and figure 4.8 a-d.

Profile one

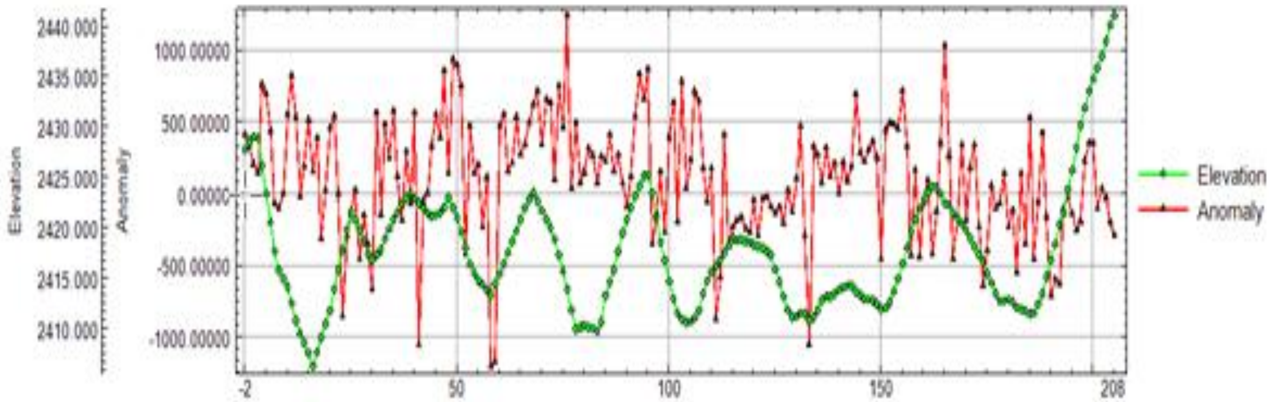


Figure 4.1-a Anomaly and elevation of magnetic profile 1

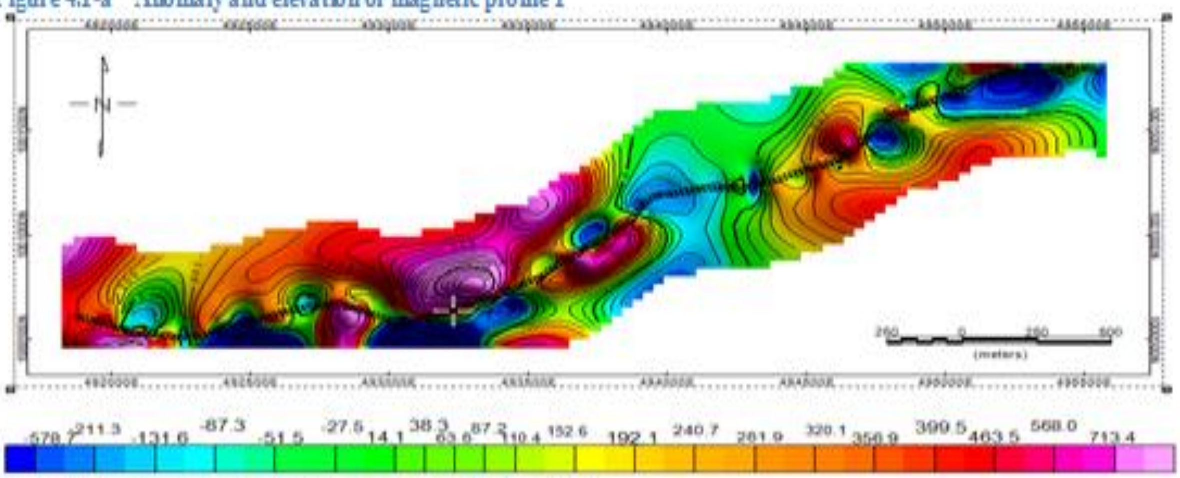


Figure 4.1-b Contour map for magnetic anomaly of profile 1

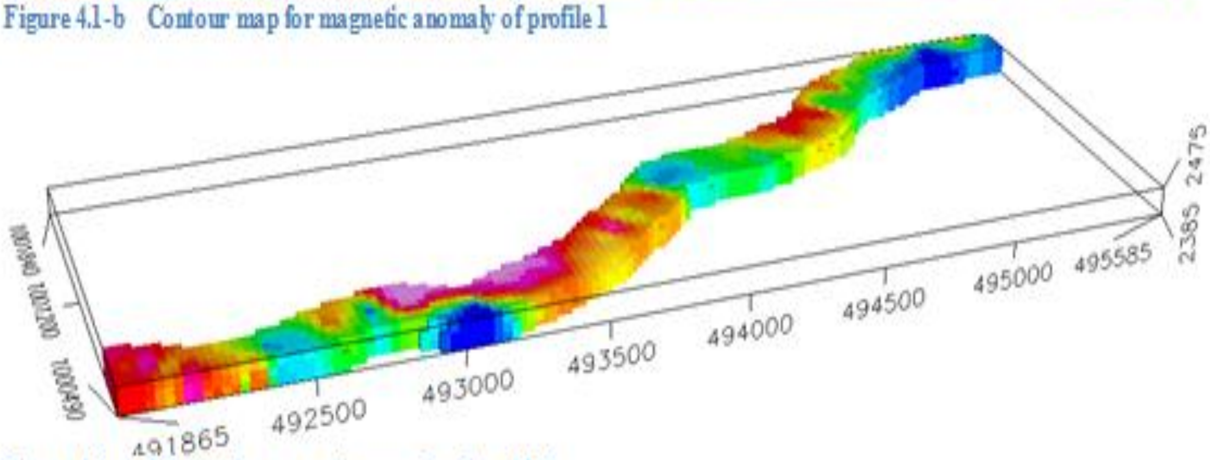


Figure 4.1-c 3D view for magnetic anomaly of profile 1

Figure 4.1a) Anomaly and elevation, b) Contour map, and c) 3D-view of magnetic anomaly of profile 1

Profile two

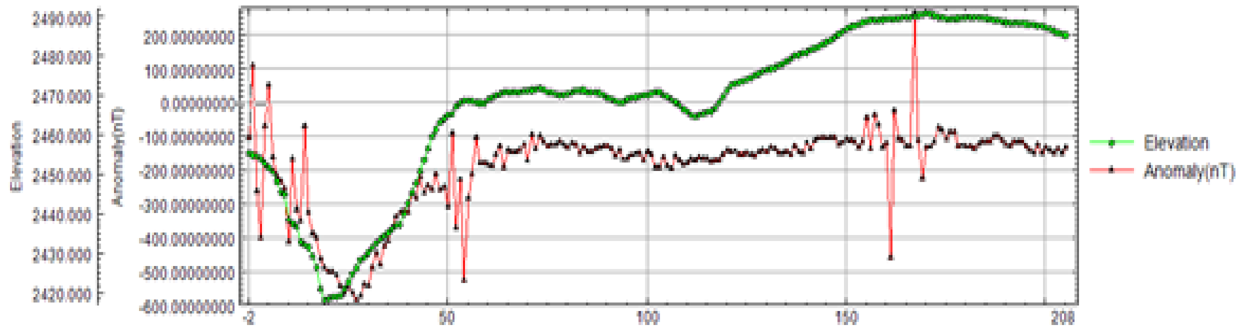


Figure 4.2-a Anomaly and elevation of magnetic profile 2

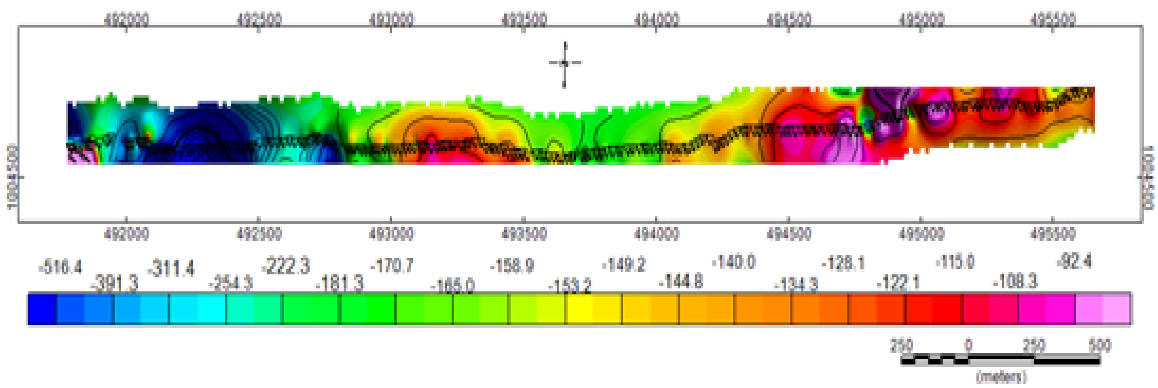


Figure 4.2-b Contour map for magnetic anomaly of profile 2

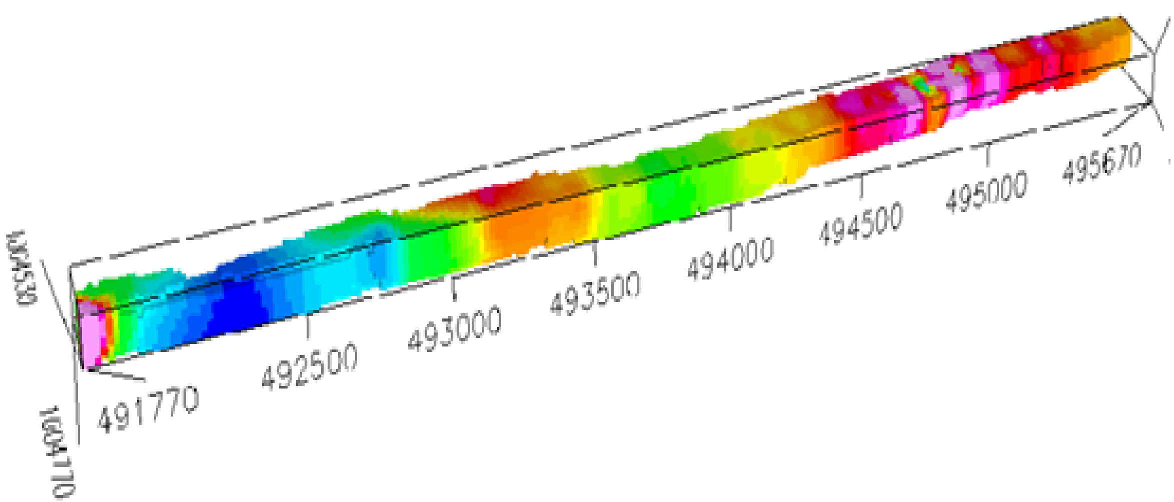


Figure 4.1-c 3D view for magnetic anomaly of profile 2

Figure 4.2 a) Anomaly and elevation, b) Contour map, and c) 3D-view of magnetic anomaly of profile 2

Profile three

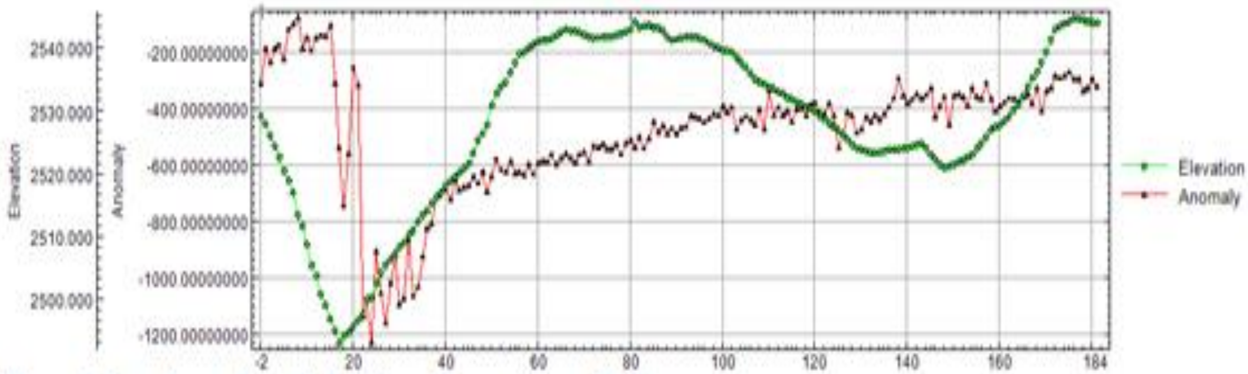


Figure 4.3-a Anomaly and elevation of magnetic profile 3

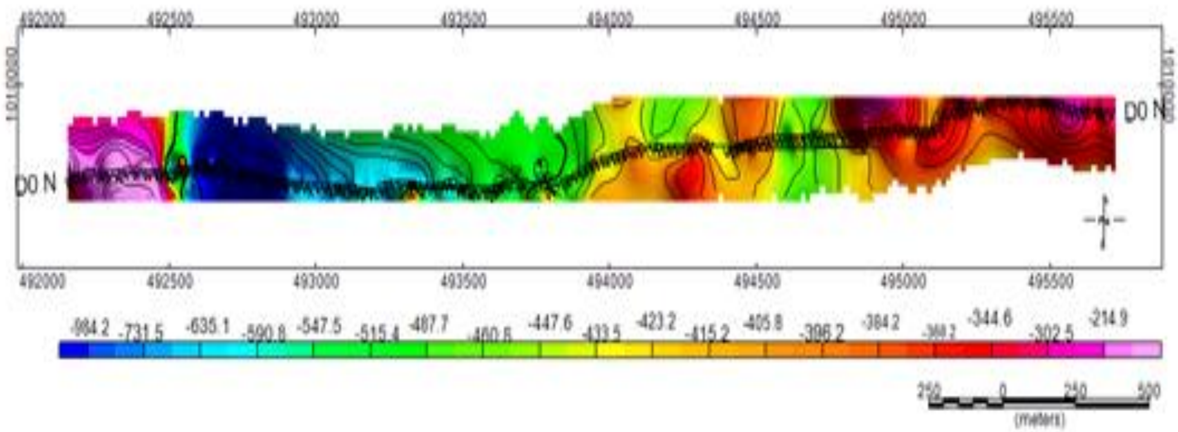


Figure 4.3-b Contour map for magnetic anomaly of profile 3

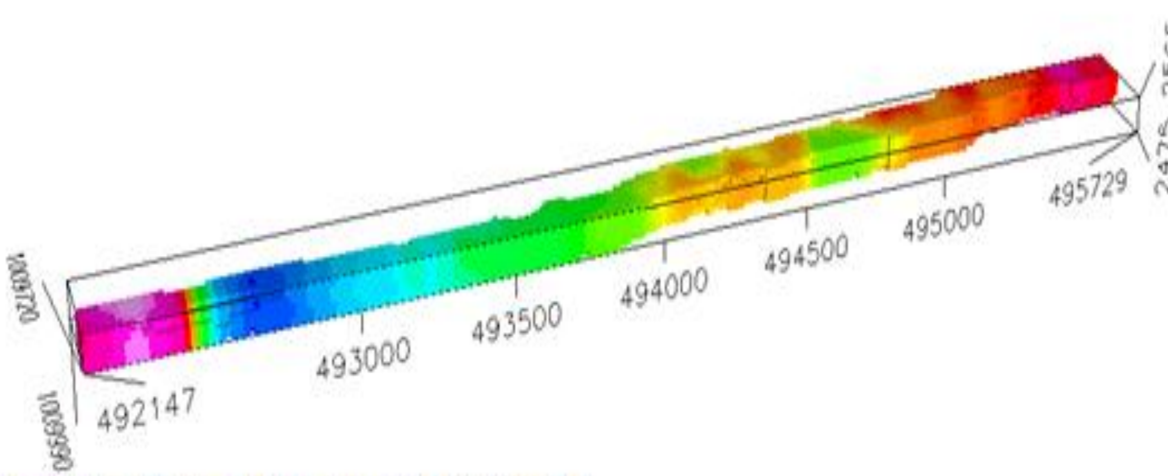


Figure 4.3-c 3D view for magnetic anomaly of profile 3

Figure 4.3a) Anomaly and elevation, b) Contour map, and c) 3D-view of magnetic anomaly of profile 3

Profile four

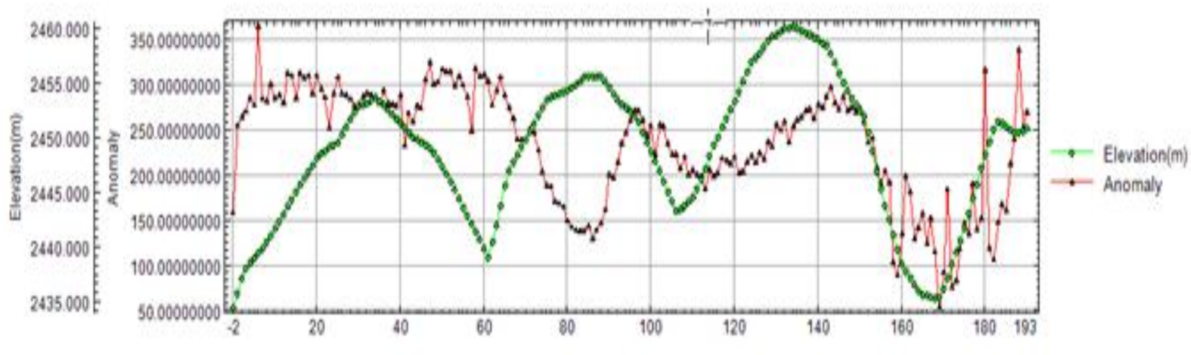


Figure 4.4-a Anomaly and elevation of magnetic profile 4

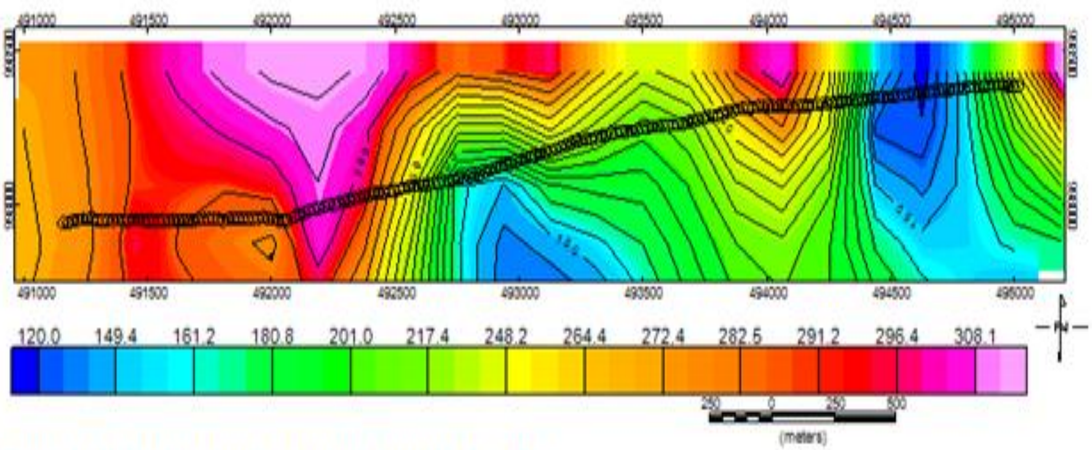


Figure 4.4-b Contour map for magnetic anomaly of profile 4

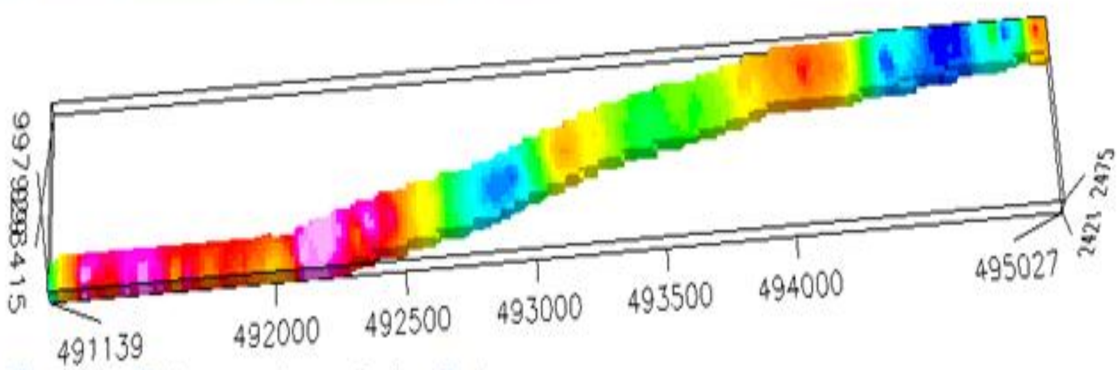


Figure 4.4-c 3D view magnetic anomaly of profile 4

Figure 4.4 a) Anomaly and elevation, b) Contour map, and c) 3D-view of magnetic anomaly of profile 4

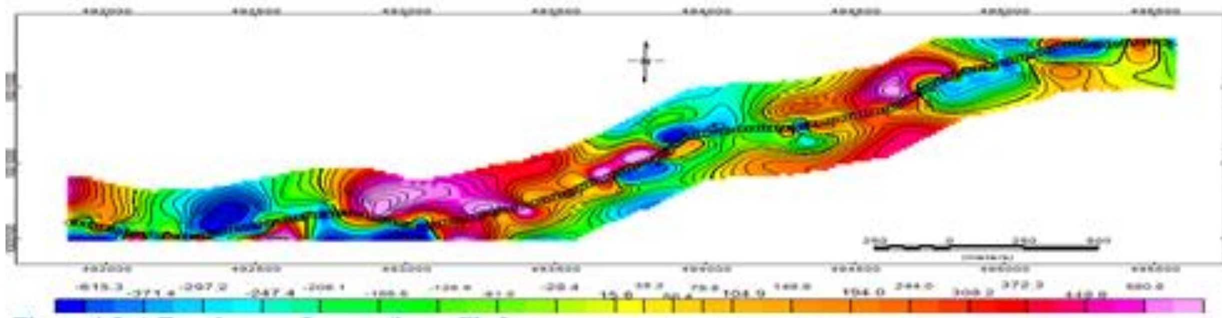


Figure 4.5 a) Trend map of magnetic profile 1

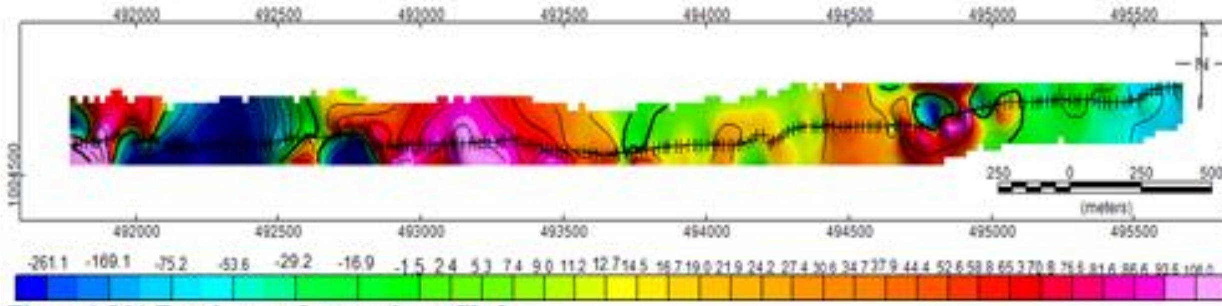


Figure 4.5 b) Trend map of magnetic profile 2

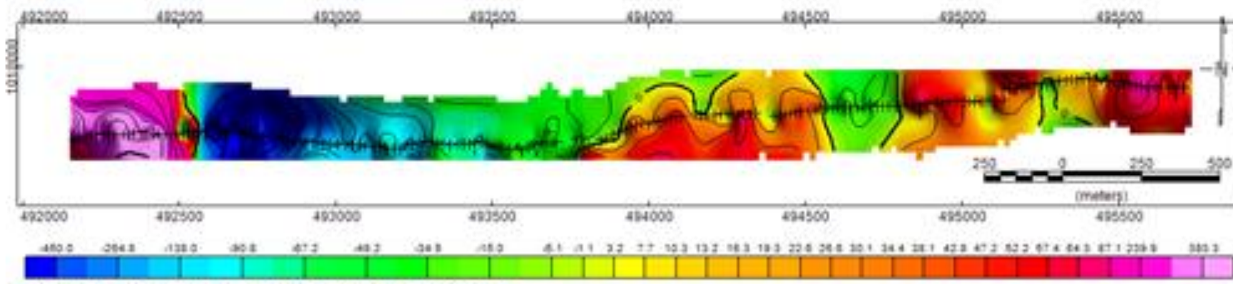


Figure 4.5 c) Trend map of magnetic profile 3

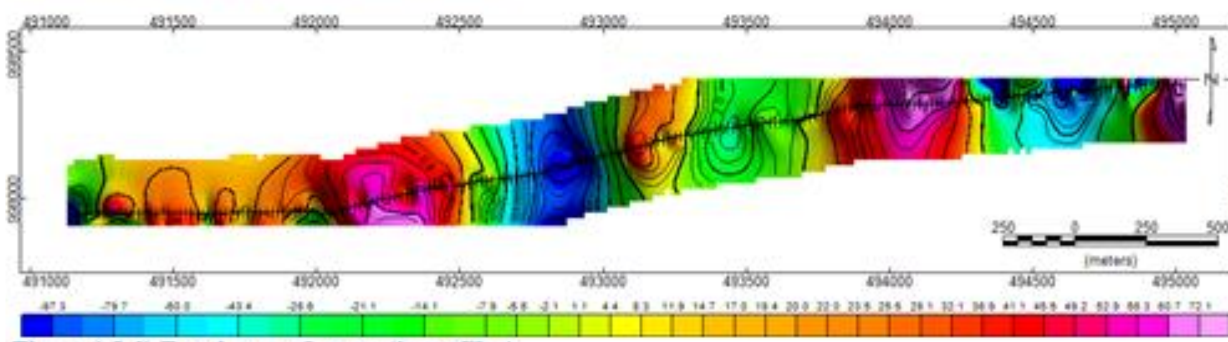


Figure 4.5 d) Trend map of magnetic profile 4

Figure 4.5 Trend map of a) Magnetic profile 1 b) Magnetic profile 2 c) Magnetic profile 3 d) Magnetic profile 4

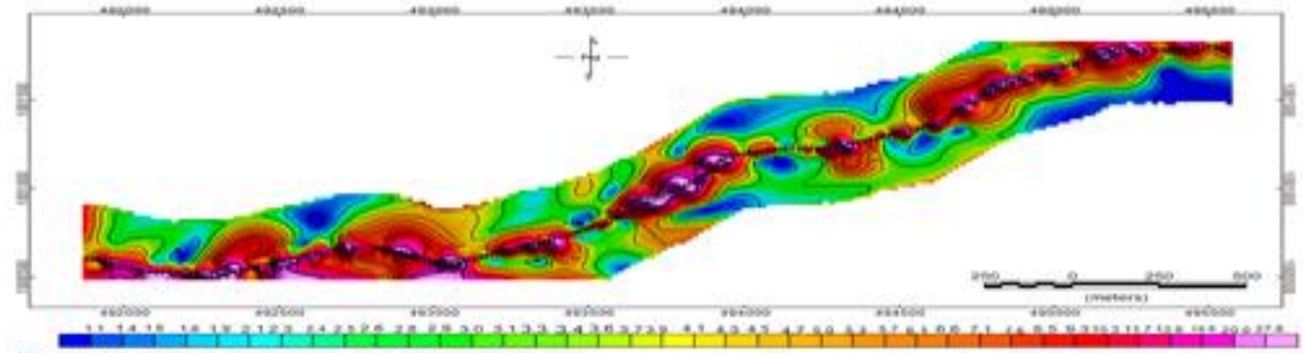


Figure 4.6 a) Analytic map of magnetic profile 1

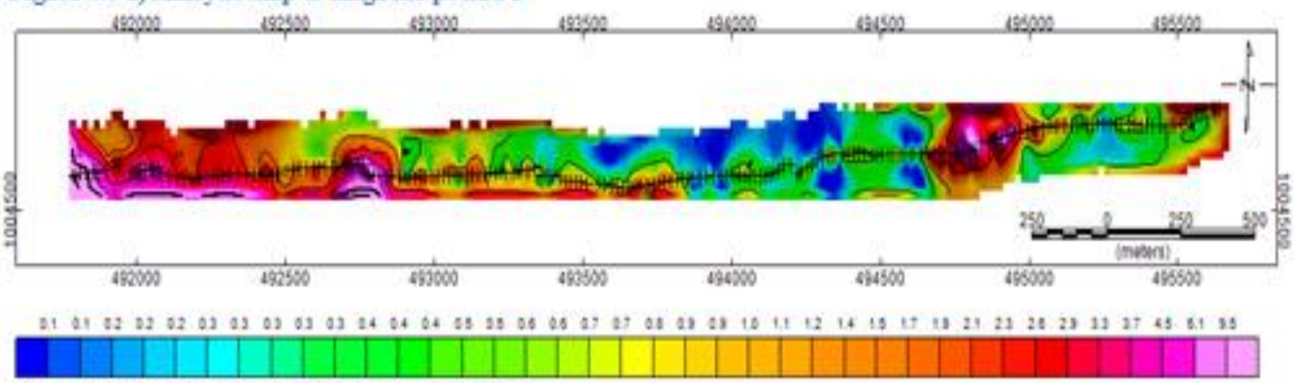


Figure 4.6 b) Analytic map of magnetic profile 2

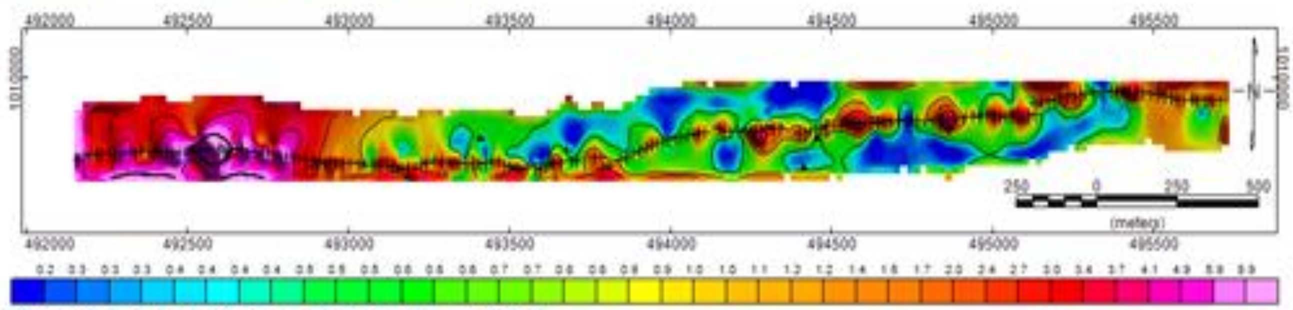


Figure 4.6 c) Analytic map of magnetic profile 3

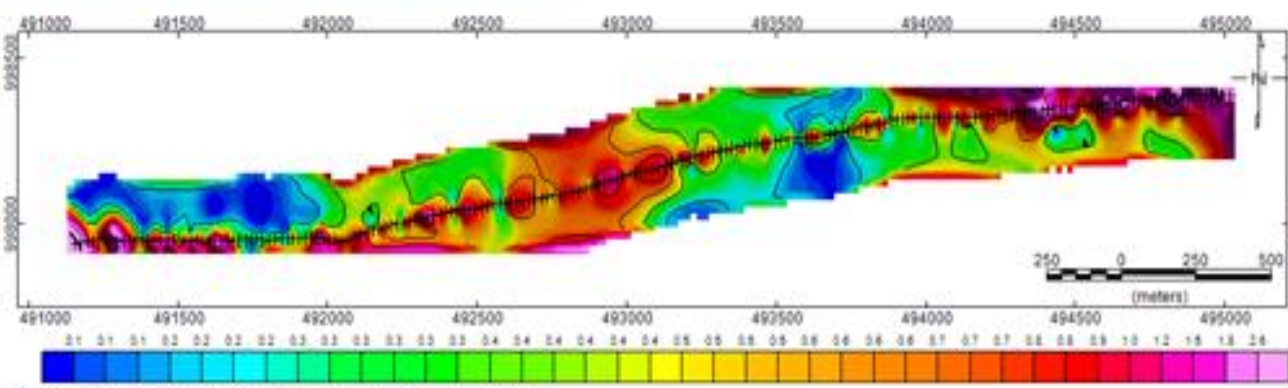


Figure 4.6 d) Analytic map of magnetic profile 4

Figure 4.6 Analytic map of a) Magnetic profile 1 b)Magnetic profile 2 c) Magnetic profile 3 d)Magnetic profile 4

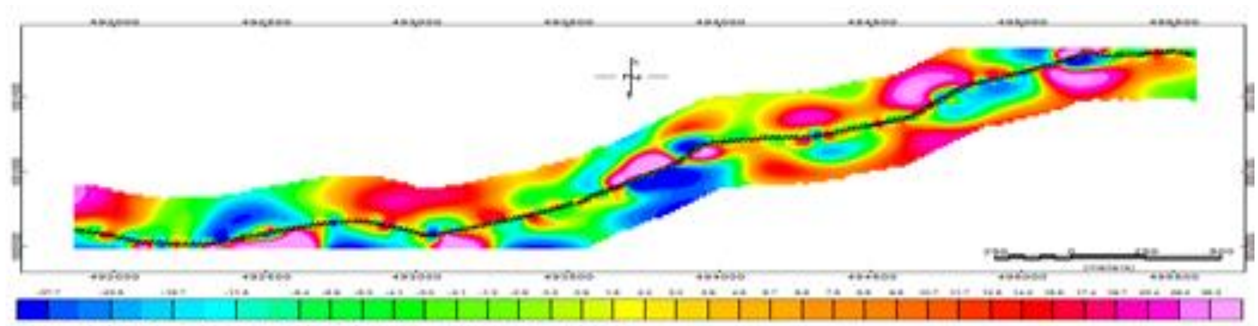


Figure 4.7 a) 1st order vertical derivative of magnetic profile 1

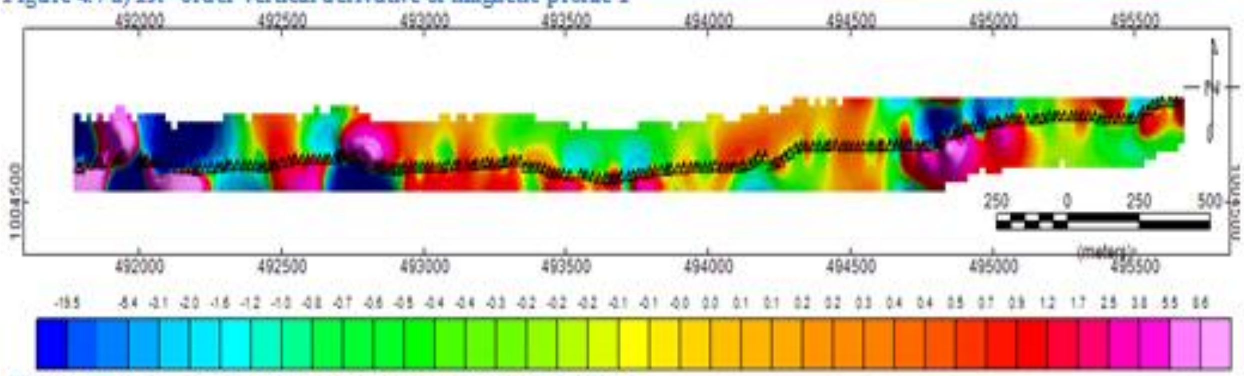


Figure 4.7 b) 1st order vertical derivative of magnetic profile 2

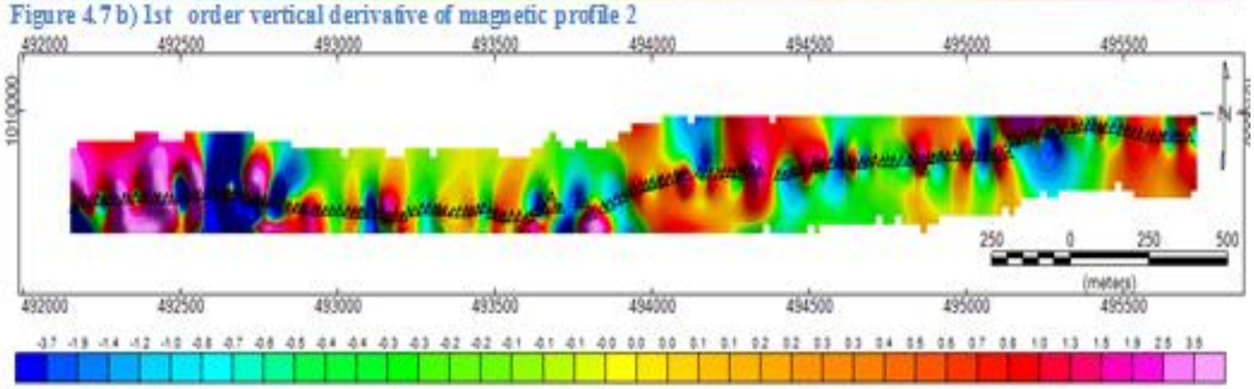


Figure 4.7 c) 1st order vertical derivative of magnetic profile 3

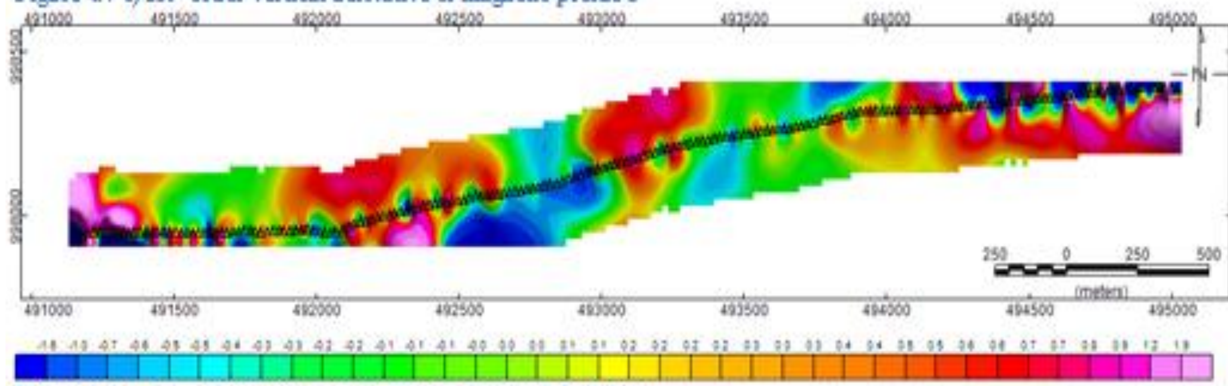


Figure 4.7 d) 1st order vertical derivative of magnetic profile 4

Figure 4.7 1st order Vertical derivative of a) Magnetic profile 1 b) Magnetic profile 2 c) Magnetic profile 3 d) Magnetic profile 4

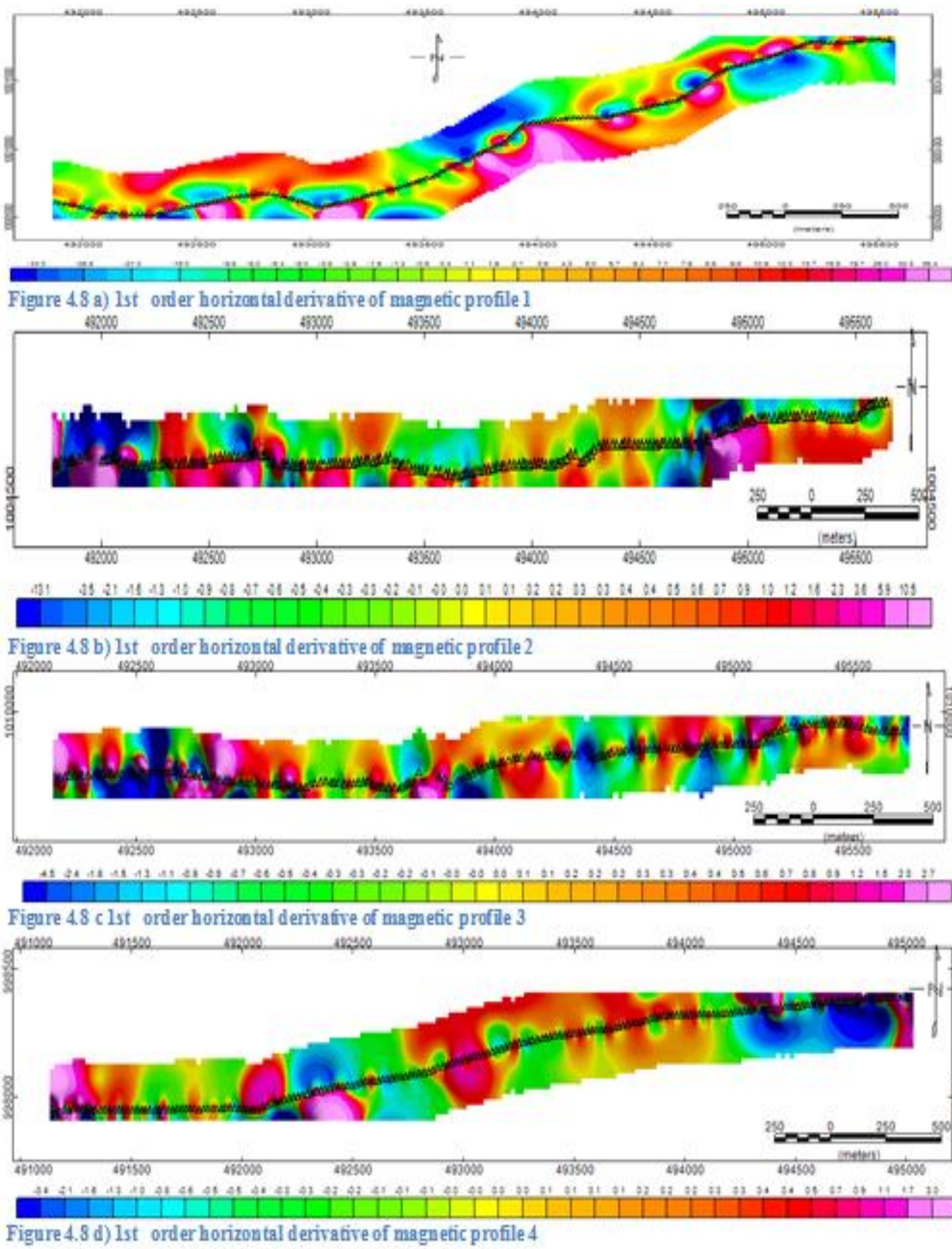
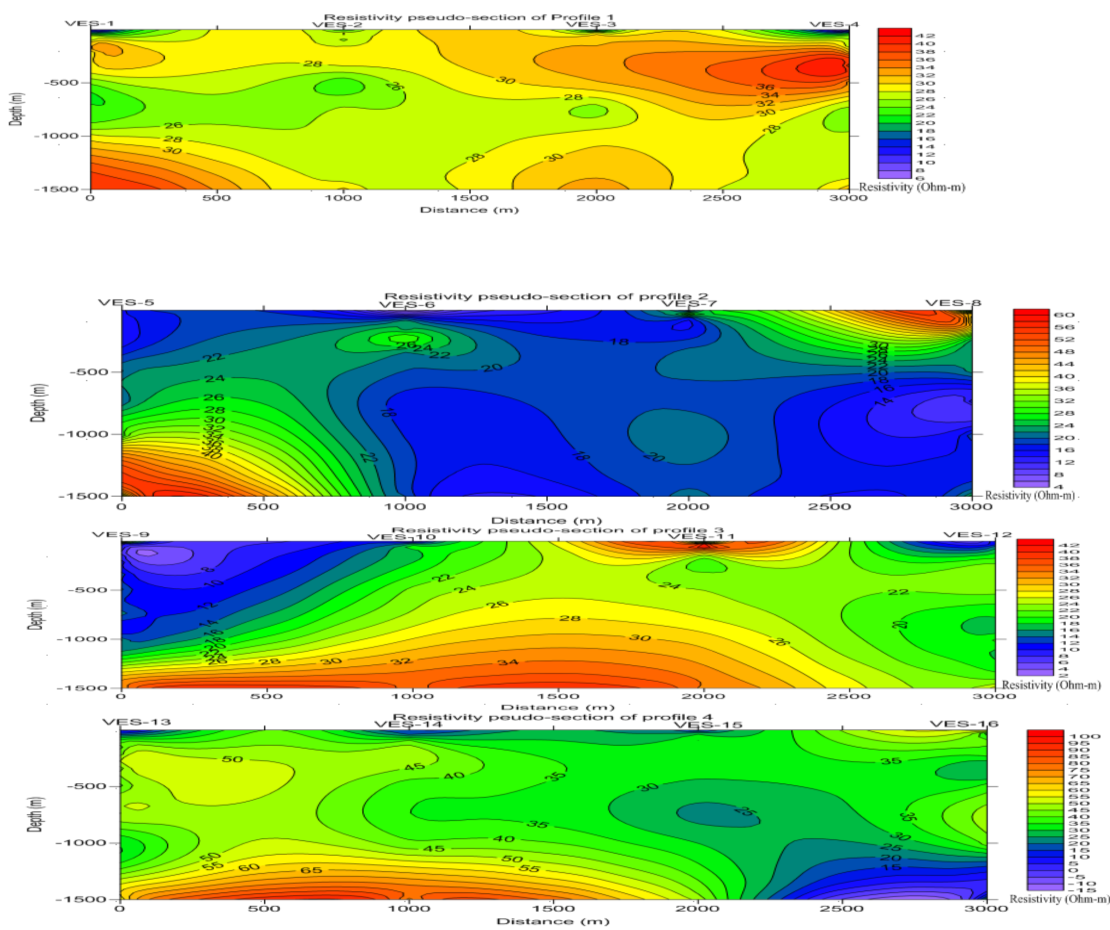


Figure 4.8 1st order horizontal derivative of a) Magnetic profile 1 b) Magnetic profile 2 c) Magnetic profile 3 d) Magnetic profile 4

4.3.2 VES Data processing

The observed apparent resistivity at each VES point was plotted against half current electrode separation (AB/2) on a double logarithmic paper of modules 62.5mm. Manually processed VES employed were by using partial curve matching techniques where two layer master and auxiliary curves. The plotted apparent resistivity curves and pre-calculated theoretical curves were compared by curve matching for the given earth model until the best fit was obtained and layer parameters, resistivity and thickness, were calculated. These parameters and the field data were used as an input data for software processing. During data processing the root mean square (RMS) error observed for the best model for all the16 interpreted VES curves, generally varied between 1.6% and 3.9 % (App. A).



Contour 1 Apparent resistivity pseudo-section contour

4.4 Data presentation

The apparent resistivity data obtained from the VES survey were presented as depth sounding curves by plotting the apparent resistivity along the ordinate axis and the half current electrode spacing (AB/2) along the abscissa, . This plot was made on bi-log paper. The resistivity depth sounding curves were classified based on layer resistivity combinations. For a three (3) layer case, there are four type curves, the H, K, A, and Q type curves. Any type curve can be derived from any combination of these type curves.

The magnetic data were presented in magnetic intensity curves, 3D-magnetic modeling, grid map, trend map, analytic signal map and also in magnetic model.

CHAPTER 5

5 INTERPRETATION, DISCUSSION

5.1 Interpretation

In the field investigation two geophysical methods were applied. The aim of Vertical electrical sounding is to Vertical electrical sounding is to give subsurface information. This .method includes apparent resistivity measurement of rocks and soils as a function of average depth of 500m. The resistivity of soils is a complicated function of permeability, porosity, clay mineralization, and ionic content of the pore fluids. Typical Resistivity of near surface and geologic material is heavily affected by groundwater, water is low resistivity material. Resistivity is reduced by increasing content of clay, increasing porosity, decreasing grain size and increasing ion content of groundwater.

The resistivity of rocks are widely varying depending on conditions and nature of rocks including frequency of fracturing or jointing, degree of fracturing and weathering nature and type of fracture filing materials, distribution of water within the lithological unit's etc.

It is not possible to tell about rock types from only resistivity or conductivity of rocks. Therefore, there must be utilization of the knowledge of an investigation area. Interpretation is made based on integration of results from the vertical electrical sounding, magnetic, and GPS data. Correlation between VES pseudo-section, magnetic-modeling, resistivity inverse contour, GPS data, magnetic profile, analytical signal map of magnetic intensity, contour map of magnetic intensity, 1st order horizontal and vertical derivative of magnetic intensity and also 3D- model. Generally the interpretation also includes interpretation of apparent resistivity.

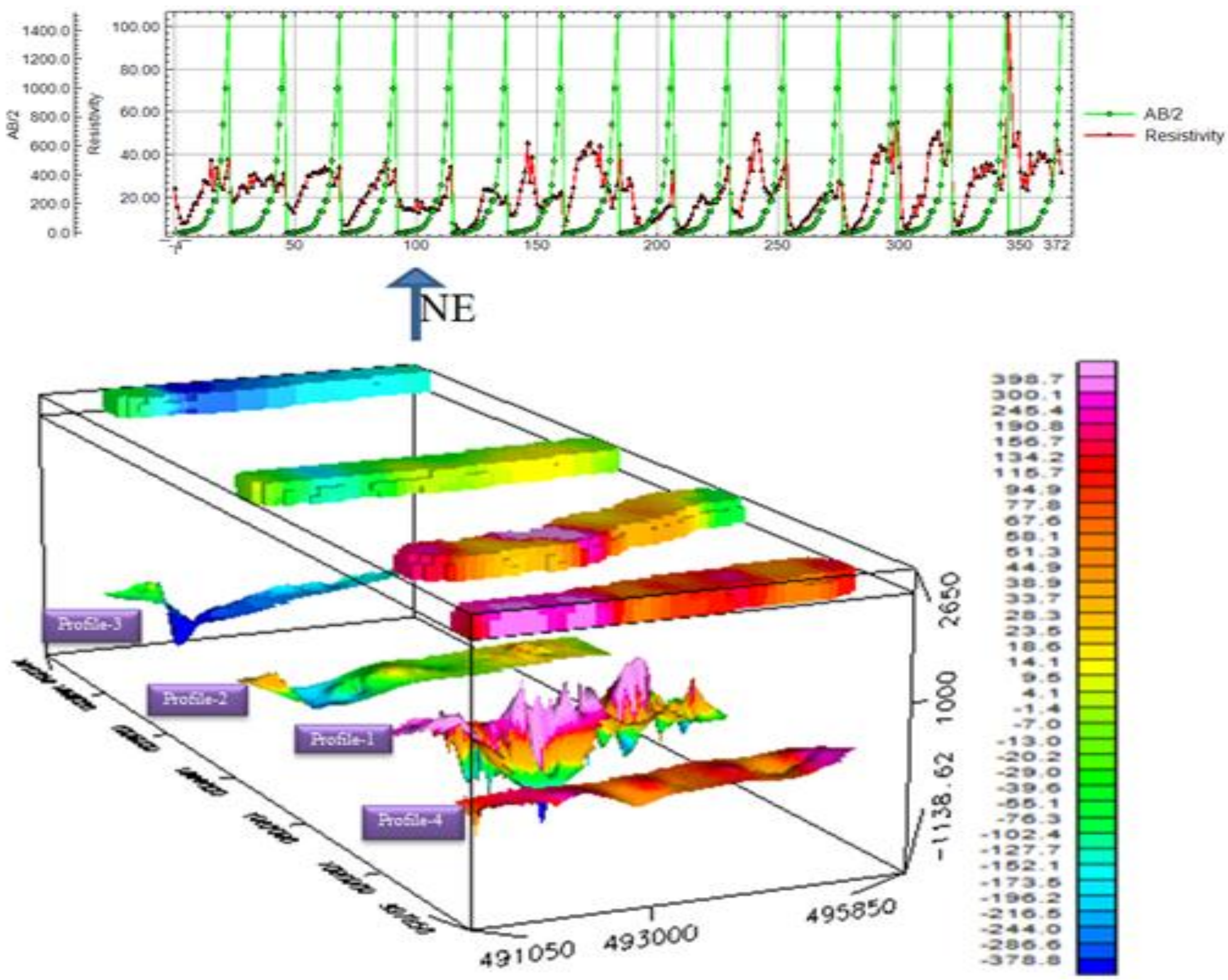
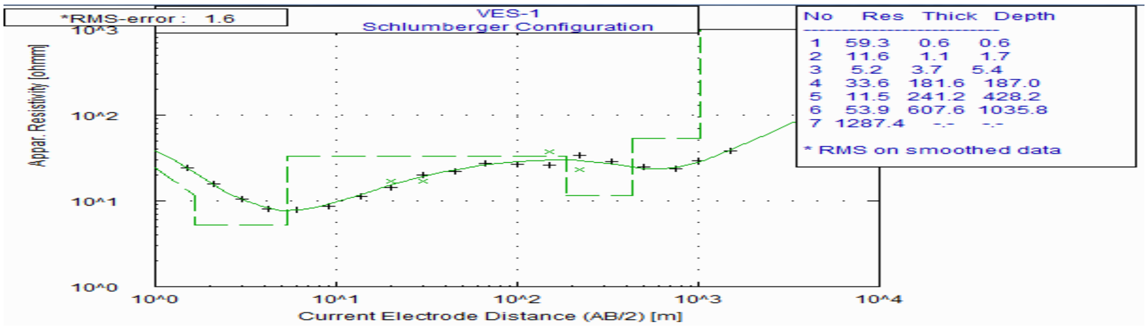
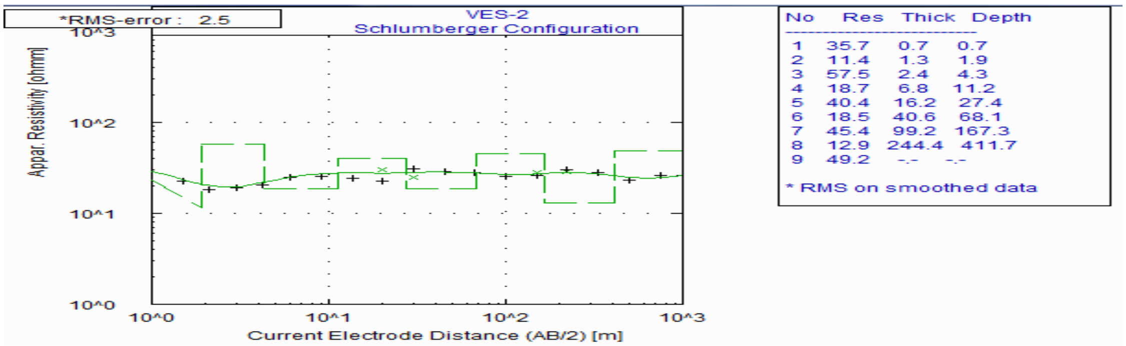


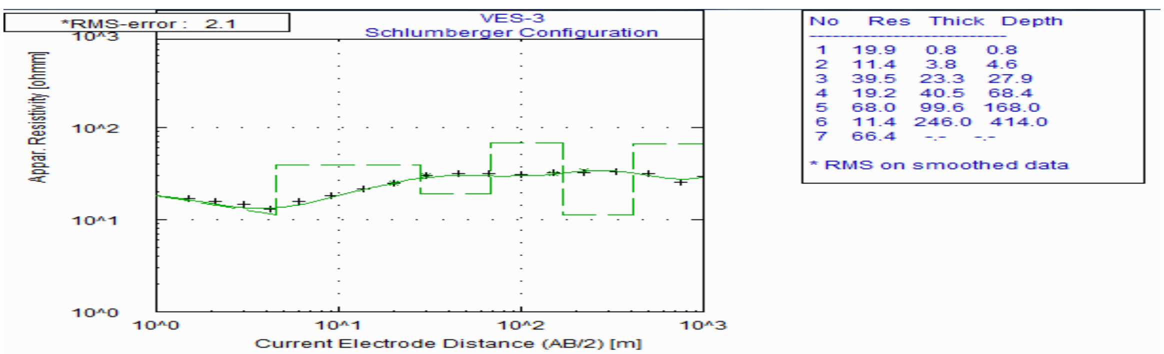
Figure 5.1 Anomaly and half electrode spacing (AB/2) and 3D-view of magnetic intensity

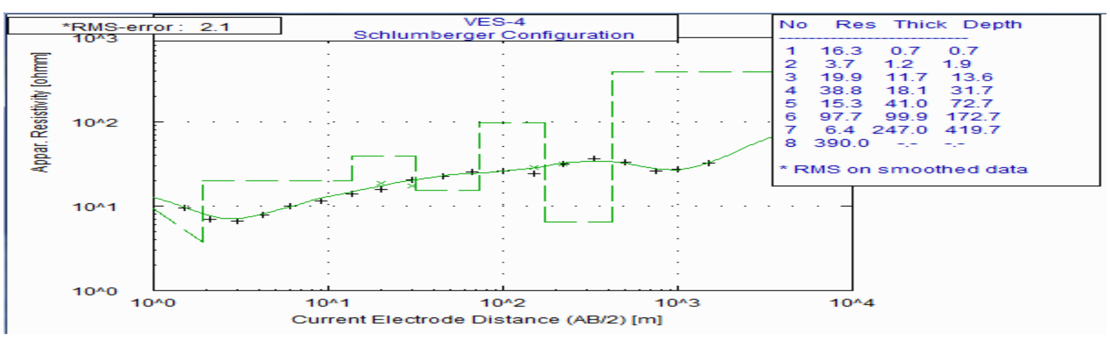
From figure 5.1 we can see that profile one is the only profile which shows very variable magnetic intensity values. Profile one show's that at the beginning of the station there is very low magnetic intensity. But profile three shows that very high Magnetic intensity and small portion of very low magnetic intensity and profile two is more or less with medium magnetic intensity.

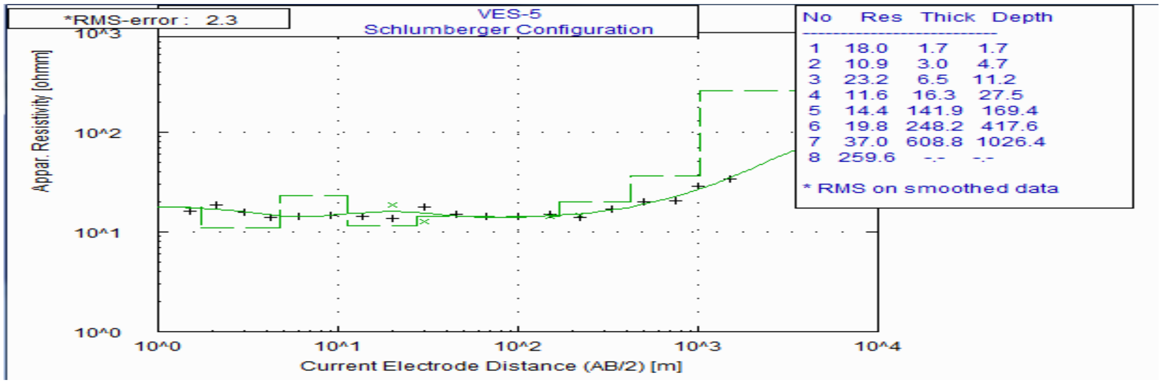
Generally apparent resistivity of VES curves, 2D depth model along all the profiles obtained from resistivity inversion and Magnetic intensity model of the four profiles is presented below.

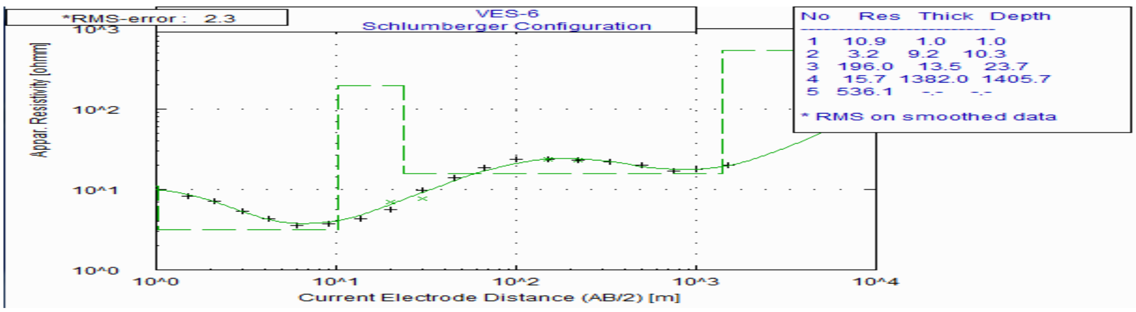

*RMS-error : 1.6
VES-1
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3 10^4
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 59.3 0.6 0.6
2 11.6 1.1 1.7
3 5.2 3.7 5.4
4 33.6 181.6 187.0
5 11.5 241.2 428.2
6 53.9 607.6 1035.8
7 1287.4 -.- -.-
* RMS on smoothed data

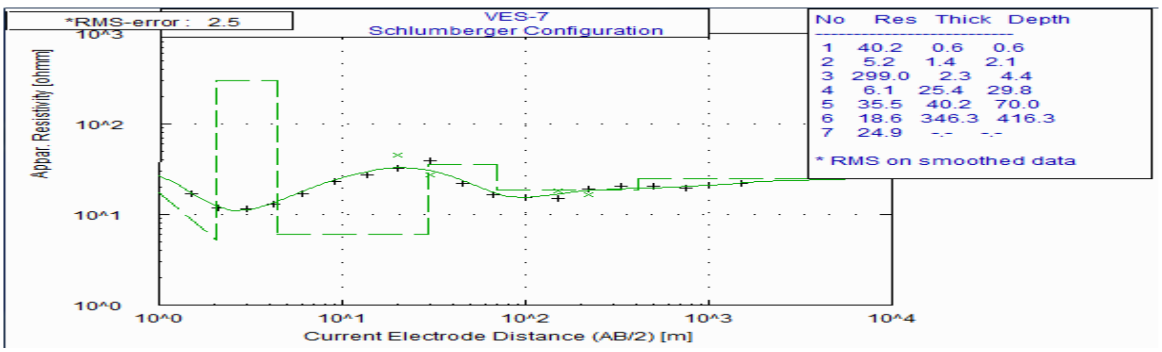

*RMS-error : 2.5
VES-2
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 35.7 0.7 0.7
2 11.4 1.3 1.9
3 57.5 2.4 4.3
4 18.7 6.8 11.2
5 40.4 16.2 27.4
6 18.5 40.6 68.1
7 45.4 99.2 167.3
8 12.9 244.4 411.7
9 49.2 -.- -.-
* RMS on smoothed data

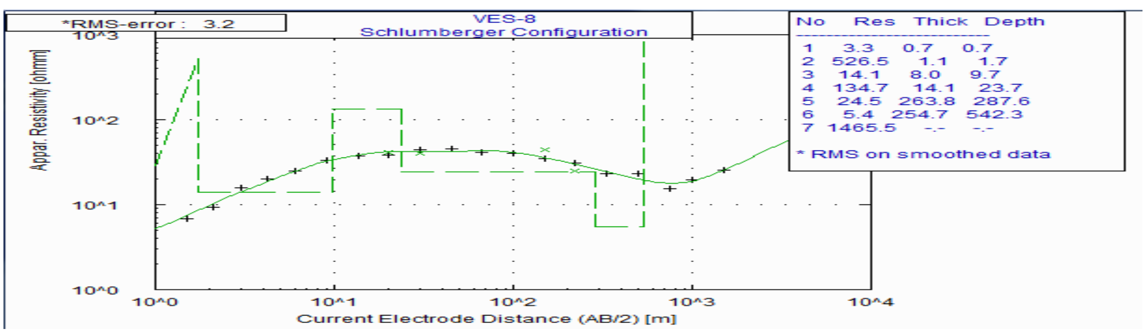

*RMS-error : 2.1
VES-3
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 19.9 0.8 0.8
2 11.4 3.8 4.6
3 39.5 23.3 27.9
4 19.2 40.5 68.4
5 68.0 99.6 168.0
6 11.4 246.0 414.0
7 66.4 -.- -.-
* RMS on smoothed data

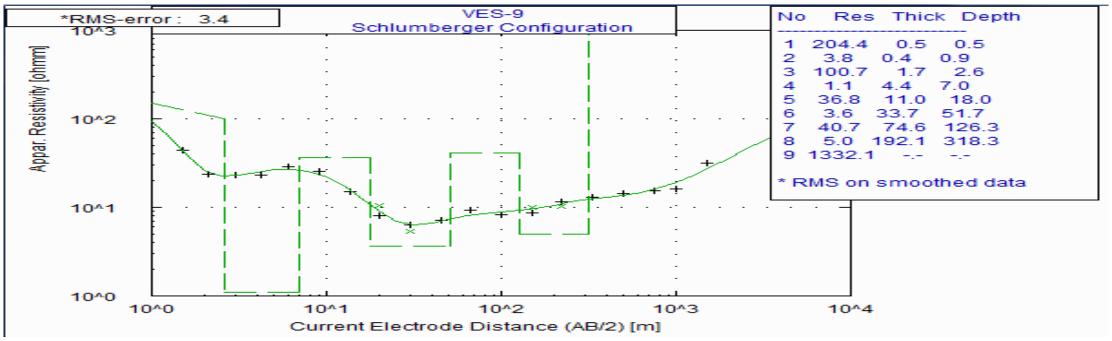

*RMS-error : 2.1
VES-4
Schlumberger Configuration
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3 10^4
Current Electrode Distance (AB/2) [m]
No Res Thick Depth
1 16.3 0.7 0.7
2 3.7 1.2 1.9
3 19.9 11.7 13.6
4 38.8 18.1 31.7
5 15.3 41.0 72.7
6 97.7 99.9 172.7
7 6.4 247.0 419.7
8 390.0 -.- -.-
* RMS on smoothed data

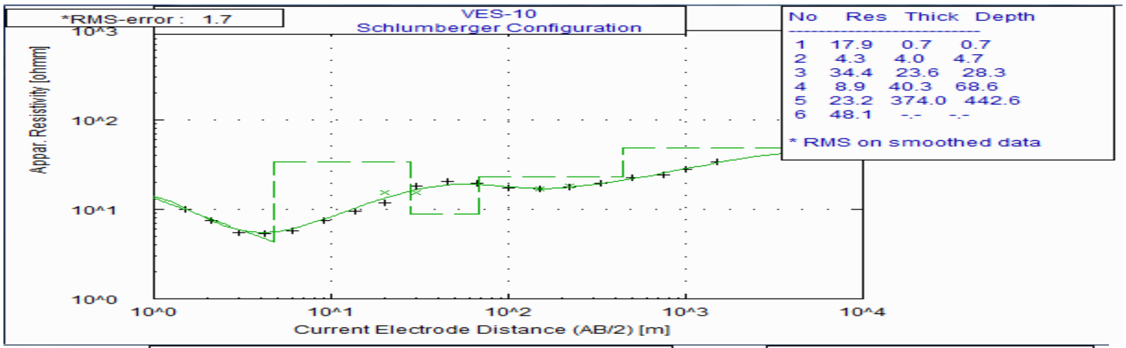

*RMS-error : 2.3
VES-5
Schlumberger Configuration
No Res Thick Depth
1 18.0 1.7 1.7
2 10.9 3.0 4.7
3 23.2 6.5 11.2
4 11.6 16.3 27.5
5 14.4 141.9 169.4
6 19.8 248.2 417.6
7 37.0 608.8 1026.4
8 259.6 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
Current Electrode Distance (AB/2) [m]

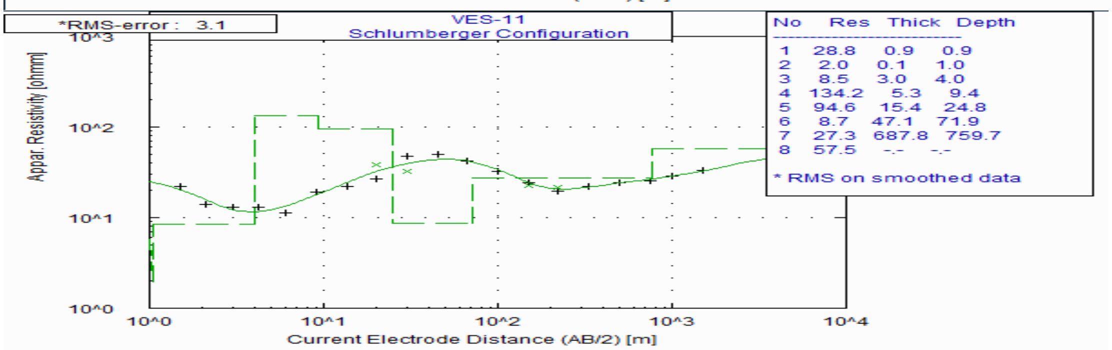

*RMS-error : 2.3
VES-6
Schlumberger Configuration
No Res Thick Depth
1 10.9 1.0 1.0
2 3.2 9.2 10.3
3 196.0 13.5 23.7
4 15.7 1382.0 1405.7
5 536.1 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
Current Electrode Distance (AB/2) [m]

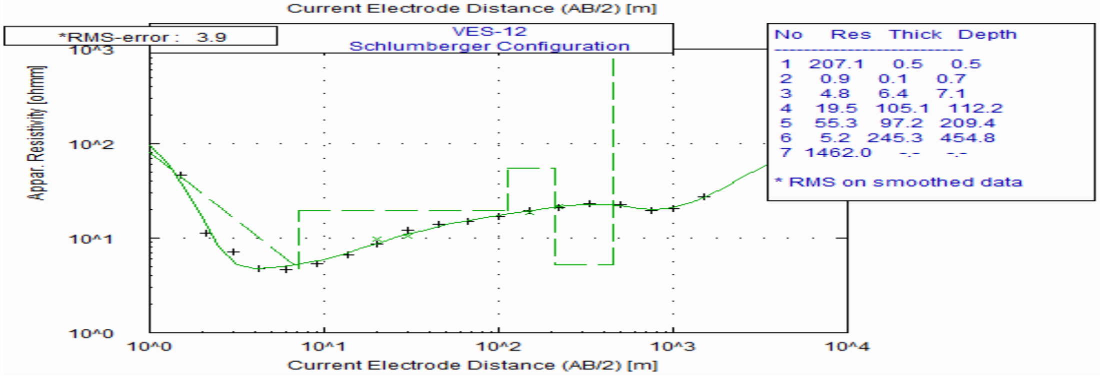

*RMS-error : 2.5
VES-7
Schlumberger Configuration
No Res Thick Depth
1 40.2 0.6 0.6
2 5.2 1.4 2.1
3 299.0 2.3 4.4
4 6.1 25.4 29.8
5 35.5 40.2 70.0
6 18.6 346.3 416.3
7 24.9 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
Current Electrode Distance (AB/2) [m]

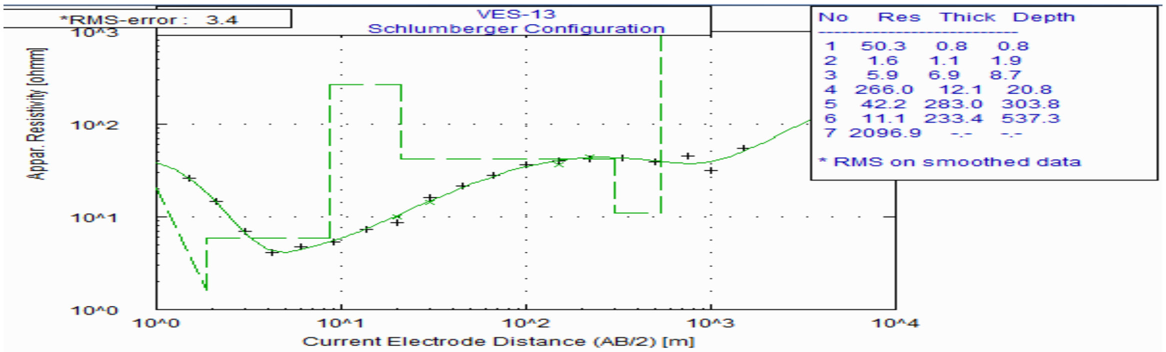

*RMS-error : 3.2
VES-8
Schlumberger Configuration
No Res Thick Depth
1 3.3 0.7 0.7
2 526.5 1.1 1.7
3 14.1 8.0 9.7
4 134.7 14.1 23.7
5 24.5 263.8 287.6
6 5.4 254.7 542.3
7 1465.5 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
Current Electrode Distance (AB/2) [m]

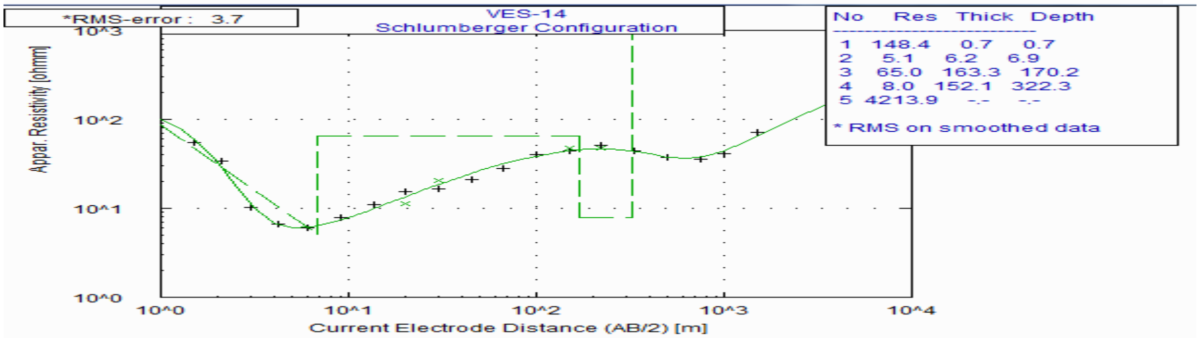

*RMS-error : 3.4
VES-9
Schlumberger Configuration
No Res Thick Depth
1 204.4 0.5 0.5
2 3.8 0.4 0.9
3 100.7 1.7 2.6
4 1.1 4.4 7.0
5 36.8 11.0 18.0
6 3.6 33.7 51.7
7 40.7 74.6 126.3
8 5.0 192.1 318.3
9 1332.1 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^0
10^1
10^2
10^3
10^4
Current Electrode Distance (AB/2) [m]

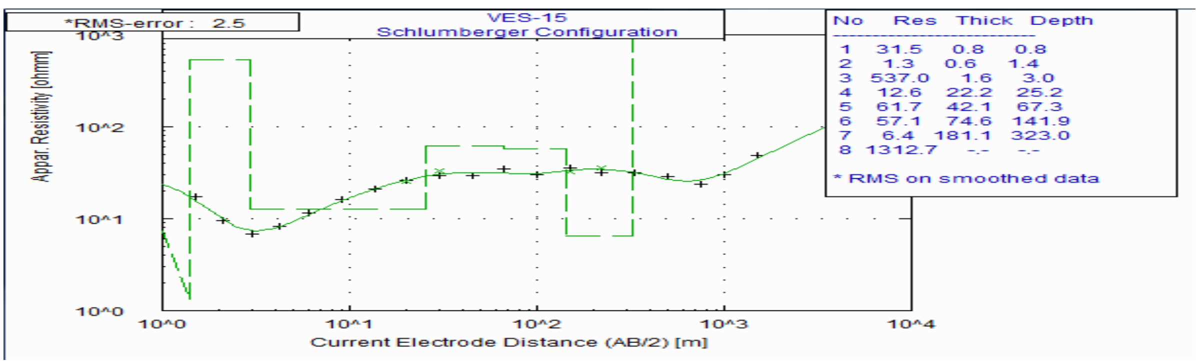

*RMS-error : 1.7
VES-10
Schlumberger Configuration
No Res Thick Depth
1 17.9 0.7 0.7
2 4.3 4.0 4.7
3 34.4 23.6 28.3
4 8.9 40.3 68.6
5 23.2 374.0 442.6
6 48.1 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^0
10^1
10^2
10^3
10^4
Current Electrode Distance (AB/2) [m]

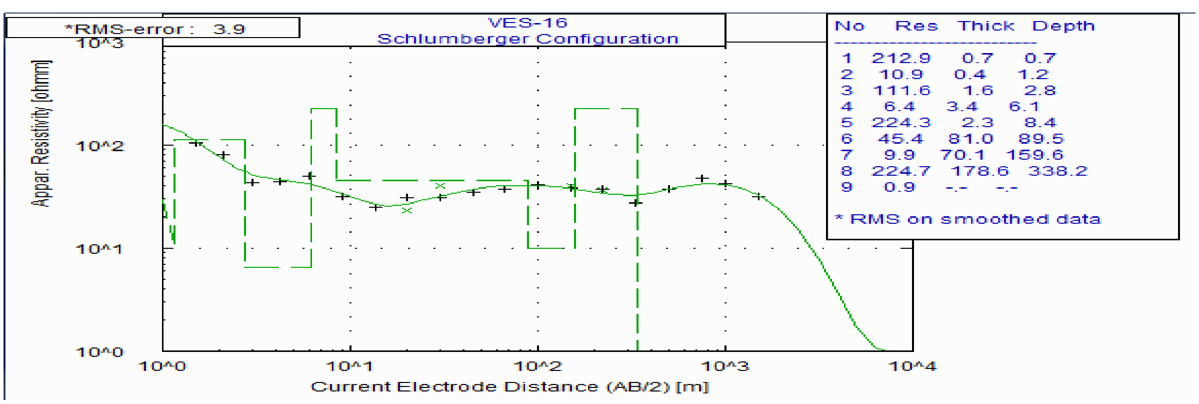

*RMS-error : 3.1
VES-11
Schlumberger Configuration
No Res Thick Depth
1 28.8 0.9 0.9
2 2.0 0.1 1.0
3 8.5 3.0 4.0
4 134.2 5.3 9.4
5 94.6 15.4 24.8
6 8.7 47.1 71.9
7 27.3 687.8 759.7
8 57.5 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^0
10^1
10^2
10^3
10^4
Current Electrode Distance (AB/2) [m]


*RMS-error : 3.9
VES-12
Schlumberger Configuration
No Res Thick Depth
1 207.1 0.5 0.5
2 0.9 0.1 0.7
3 4.8 6.4 7.1
4 19.5 105.1 112.2
5 55.3 97.2 209.4
6 5.2 245.3 454.8
7 1462.0 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^0
10^1
10^2
10^3
10^4
Current Electrode Distance (AB/2) [m]


*RMS-error : 3.4
VES-13
Schlumberger Configuration
No Res Thick Depth
1 50.3 0.8 0.8
2 1.6 1.1 1.9
3 5.9 6.9 8.7
4 266.0 12.1 20.8
5 42.2 283.0 303.8
6 11.1 233.4 537.3
7 2096.9 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3 10^4
Current Electrode Distance (AB/2) [m]


*RMS-error : 3.7
VES-14
Schlumberger Configuration
No Res Thick Depth
1 148.4 0.7 0.7
2 5.1 6.2 6.9
3 65.0 163.3 170.2
4 8.0 152.1 322.3
5 4213.9 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3 10^4
Current Electrode Distance (AB/2) [m]


*RMS-error : 2.5
VES-15
Schlumberger Configuration
No Res Thick Depth
1 31.5 0.8 0.8
2 1.3 0.6 1.4
3 537.0 1.6 3.0
4 12.6 22.2 25.2
5 61.7 42.1 67.3
6 57.1 74.6 141.9
7 6.4 181.1 323.0
8 1312.7 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3 10^4
Current Electrode Distance (AB/2) [m]


*RMS-error : 3.9
VES-16
Schlumberger Configuration
No Res Thick Depth
1 212.9 0.7 0.7
2 10.9 0.4 1.2
3 111.6 1.6 2.8
4 6.4 3.4 6.1
5 224.3 2.3 8.4
6 45.4 81.0 89.5
7 9.9 70.1 159.6
8 224.7 178.6 338.2
9 0.9 -.- -.-
* RMS on smoothed data
Appar. Resistivity [ohmm]
10^3
10^2
10^1
10^0
10^0 10^1 10^2 10^3 10^4
Current Electrode Distance (AB/2) [m]

VES Number	Geographical Location	Resistivity of Layer	Layer Thickness	Depth
		ρ_1 / ρ_2 / … /ρ_n (ohm-m)	h_1/ h_2 /…/h_n (m)	D_1/D_2/--/D_n (m)
1 (T1-00) /VES-1	38.93303408°E 9.05357610° N	59/12/5/34 /12/54/1287	0.6/1.1/3.7/181.6/241.2/607.6/--	0.6/1.7/187/428.2/1035/--
2 (T1-1100) /VES-2	38.94156872°E 9.05702373° N	36/11/58/19/40/19/45/1 3/49	0.7/1.3/2.4/6.8/16.2/40.6/99.2/244 .4/--	0.7/1.9/4.3/11.2/27.4/68.1/167.3/411. 7/--
3 (T1-2100) /VES-3	38.94998526°E 9.06019979° N	20/11/40/19/68 /11/66	0.8/3.8/23.3/40.5/99.6/246/--	0.8/4.6/27.9/68.4/168/414/--
4 (T1-30050) /VES-4	38.95763762°E 9.06309517° N	16/4/20/39/15/98/6/390	0.7/1.2/11.7/18.1/41/99.9/247/--	0.7/1.9/13.6/31.7/72.7/172.7419.7
5 (T2-00) /VES-5	38.93045197°E 9.08990956° N	11/3.2/196/15.7/536.1	1/9.2/13.5/138/--	1/10.3/23.7/14.5/-
6 (T2-1000) /VES-6	38.93929727°E 9.09084278° N	18/11/23/12/14/20/37/2 59	1.7/3/6.5/16.3/142/248.2/608/--	1.7/4.7/11.2/27.5/169.5/417.6/1026/--
7 (T2-2000) /VES-7	38.94797881°E 9.09181194° N	40/5/299/6/36/19/25	0.6/1.4/2.3/25.4/40.2/346.3/--	0.6/2.1/4.4/30/70/416.3/--
8 (T2-3000) /VES-8	38.95737029°E 9.09225636° N	204/4/101/1/37/3.6/41/5 /1332	0.5/0.4/1.7/4.4/11/33.7/74.6/192	0.5/0.9/2.6/7/18/51.7/126.3/318.3/-
9 (T3-00) /VES-9	38.93210836°E 9.13737815° N	3/527/14/135/25/5/1465	0.7/1.1/8/14/264/254/-	0.7/1.7/9.7/24/288/542/-
10 (T3-1000) /VES-10	38.93210836°E 9.13737815° N	18/4/34/9/23/48	0.7/4/23.6/40.8/374/	0.7/4.7/28.3/68.6/442.6/-
11 (T3-2000) /VES-11	38.94912811°E 9.13737189° N	29/2/9/134/94/9/27/58	0.9/0.1/3/5.3/15.4/47.1/687.8/-	0.9/1/4/9.4/24.8/71.9/759.7/-
12 (T3-3000) /VES-12	38.95800202°E 9.13763533° N	207/1/5/20/55/5/1462/	0.5/0.2/6.4/105/97/245/-	0.5/0.7/7.1/112/209.4/454.8/-
13 (T4-00) /VES-13	38.92562289°E 9.03028365° N	50/2/6/266/42/11/2097	0.8/1.1/7/12/283/233.4/-	0.8/1.9/8.7/20.8/303.8/537.3/-
14 (T4-1000) /VES-14	38.93475796°E 9.03080096° N	148/5/65/8/42/3	0.7/6.2/163.3/152/-	0.7/7/170/322.3/-
15 (T4-2000) /VES-15	38.94388395°E 9.03139040° N	32/1/537/13/62/57/6/13 13	0.8/0.6/1.6/22/42/75/181/-	0.8/1.4/3/25.2/67.3/142/323/-
16 (T4-3000) /VES-16	38.95316464°E 9.03206103° N	213/11/112/6/224/45/10 /225/1	0.7/0.5/1.6/3.4/2.3/81/70/179/-	0.7/1.2/2.8/6.1/8.4/90/160/338.2/-

Table 5-1 Apparent resistivity, thickness depth, layer and geographical location of VES1 - VES 16

5.1.1 Profile one

The line of profile 1 runs over the central part of the study area in the direction of W-E. There are four resistivity soundings which are positioned at a distance of 0m, 1100m, 2100m, and 3050m for VES 1, 2, 3 and 4 respectively, from the west to east. The magnetic anomaly and elevation graph, apparent resistivity section and magnetic model of profile one is given in figure 5.2-5.4. The line extends from station 0 m to station 4100 m. The first and the last observation points correspond to the points marked by UTM coordinates 491880E, 1000608 and 495552E, 1001787N within zone 37. The ground elevation is between elevations 2395ma.s.l and 2440ma.s.l.

The uppermost part of profile line one is represented by a resistivity varying from 0.6-40 Ohm-m with depth up to greater than 600m. This is very low resistivity and is associated with decomposed materials. The resistivity values between 20-40 Ohm-m are interpreted as comprising of stiff clay, highly decomposed and fractured volcanic rocks tuff and ash.

As we go deeper there is a very low resistivity starting from station 1000 m and depth of about 600m towards station 3000m which is less deeper starting from about 500m depth. At station from 2000m-2150 and depth from 100m-250m and from station 2750-3000m with depth from 80m-380 m there is high resistivity material with resistivity value varying from 60-140 Ohm-m. This is interpreted as slightly fractured volcanic rocks.

Due to the hydrogeological information of the area, the station from 0 to2000 m is probably expected to be ground water potential zone. Here minimum depth to bed rock is expected at Geological structures are inferred between stations 0 and 1200m, around station 1100 and 900m, between stations 1500m and 2200m around 1650m and 2100m between stations 2500m and 3000m around 2850m. VES1, VES2 VES3 and VES4 tells us that there is similar extension of the geology means they are almost similar. Figure 5.3 below shows as 2D depth model along profile one obtained from resistivity inversion. The VES interpretation is also based on the apparent resistivity contour given on appendix-A and the resistivity value of some geologic formations given on Appendix-B

From the magnetic profile, the data can be interpreted as follows. The magnetic response between stations 0m and 1000m,1500m and 2000m and between 2700- the end of the profile is variable having high amplitude and probably reflects possible geological contact or structure. Within the zone between 2100m and 2650m the magnetic profile suggests relatively low amplitude. Detail interpretation of the magnetic response requires knowledge of local geology. Fig 5.2 below shows the magnetic anomaly and elevation graph. Fig 5.4 shows the model of the magnetic intensity of profile one.

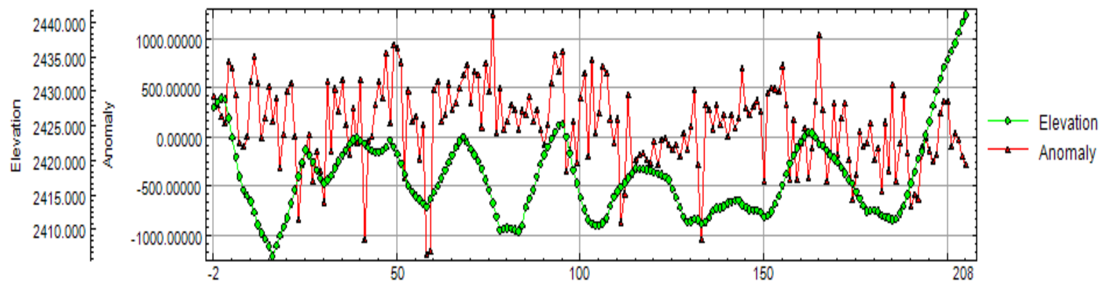


Figure 5.2 Magnetic anomaly and elevation of profile-1

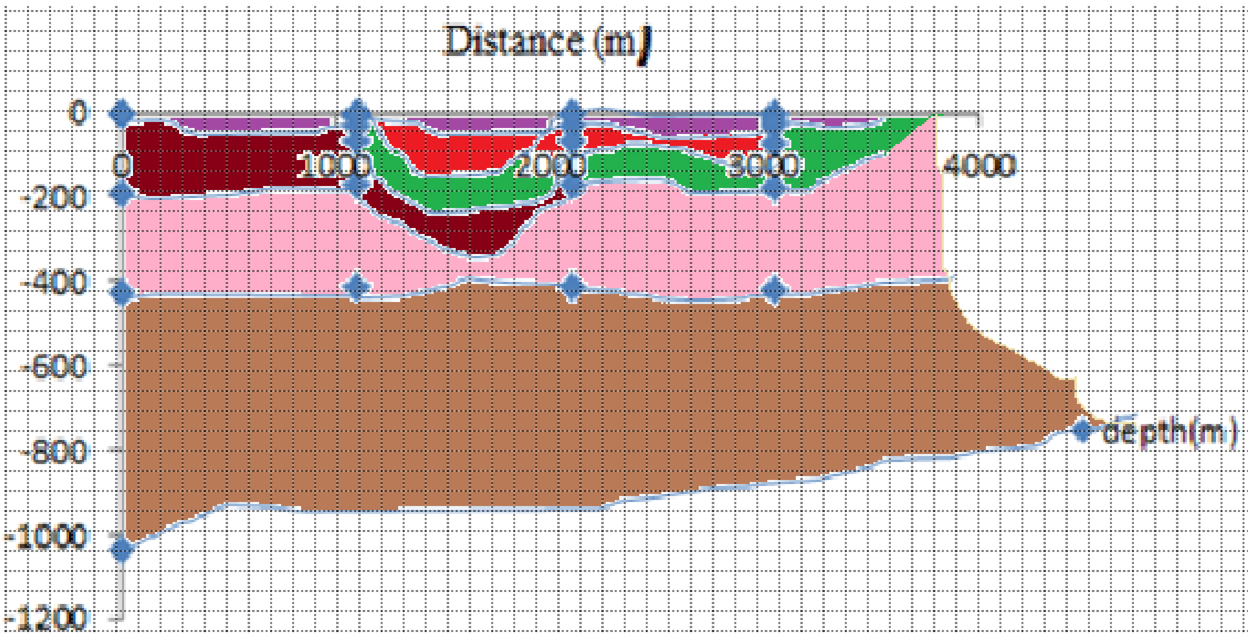


Figure 5.3 2D depth model along profile one obtained from resistivity inversion

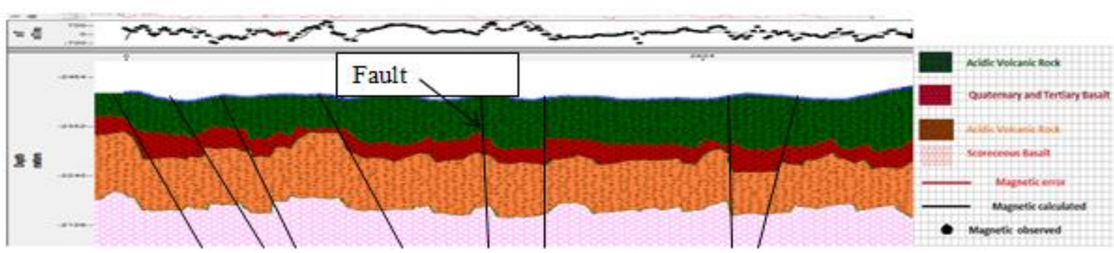


Figure 5.4 Magnetic model of profile 1

5.1.2 Profile two

Profile 2 runs over the northern part of profile one and to the south of profile 3. There are four resistivity soundings which are positioned at a distance of 0m, 1000m, 2000m, and

3000m for VES 5, 6, 7 and 8 respectively, from the west to east. The Magnetic anomaly and elevation graph, Resistivity pseudo section and magnetic model of profile two is also given in figure 5.5 - 5.7. The line extends from station 0m to station 4100m.The first and the last observation points correspond to the points marked by UTM coordinates 491785E, 1004590N and 495642E, 1004590N within zone 37. The ground elevation is between elevations 2420ma.s.l and 2500ma.s.l.

The VES profile line two is represented by a resistivity varying from 0.08-400 Ohm-m. The resistivity values less than 50 Ohm-m is interpreted as highly decomposed and fractured volcanic rocks. There is a high resistivity material starting from station 700 m to 1700 m with depth of about 200m, 1700m to 2200m which is a very thin layer with about 40m depth and from station 2300 to 3000m with depth about 160m ranging from 50-400Ohm-m. Generally except from station 0m to 700m which is comprises of low resistivity up to the depth of about 800m the remaining portion is also with low resistivity and interpreted as partially fractured rocks of volcanic type.

Due to the information of the area, the station from 0 to700 m is probably expected to be ground water potential zone. Expected geological structures are inferred between stations 0 and 700m, around station 1000, 2000m, and around 2700m .curves of VES6, VES7 and VES8 shows existence of similar geologic formation except VES 5 i.e. a little difference from the three. Figure 5.6 below shows as 2D depth model along profile one obtained from resistivity inversion. The VES interpretation is also based on the apparent resistivity contour given on appendix-A and the resistivity value of some geologic formations given on Appendix-B

From the magnetic profile, the data can be interpreted as follows. There is a very low magnetic response between stations 0m and 1000m, decreasing from 0 to 500m and increasing from 500m to 1000m extending up to the depth above 600m. Between 1500m and 2800m the profile is not variable having small amplitude and probably reflects there is no possible geological contact or structure. Within the zone between 2800m and 3200m the magnetic profile suggests the presence of geological structure with very high amplitude. Fig 5.5 below shows the magnetic anomaly and elevation graph. Fig 5.7 shows the model of the magnetic intensity of profile two. The general low amplitude of the magnetic profile along line two may indicate less surface exposure of the volcanic rocks, especially most parts of the eastern part of the profile.

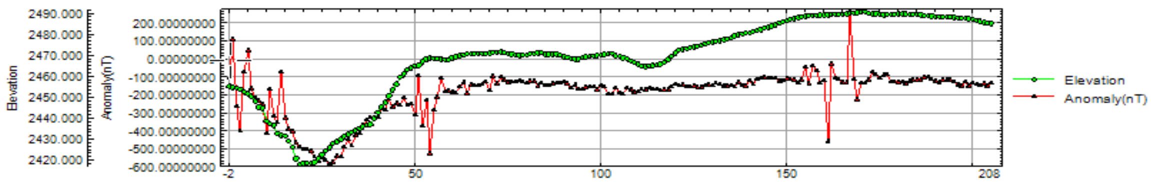


Figure 5.5 Magnetic anomaly and elevation of profile-2

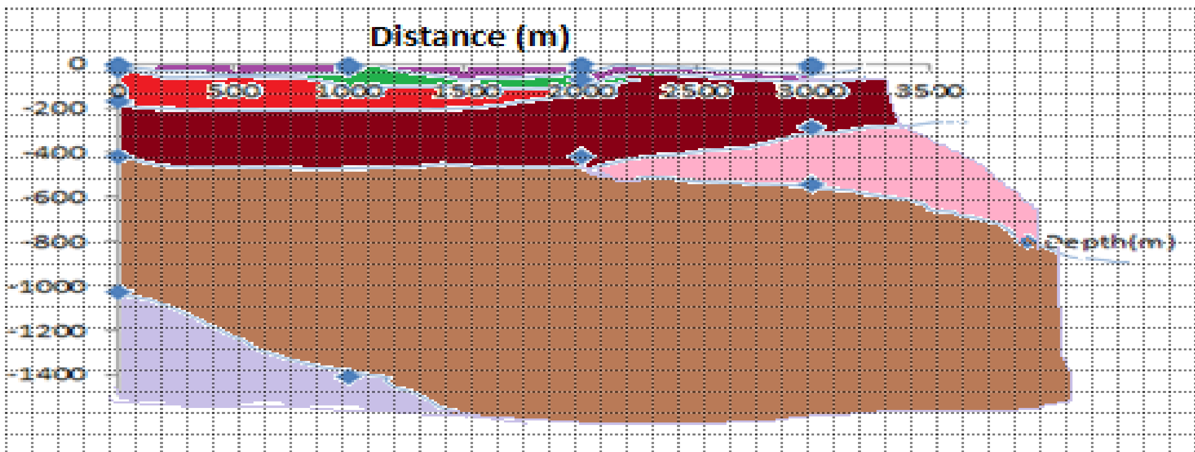


Figure 5.6 2D depth model along profile two obtained from resistivity inversion

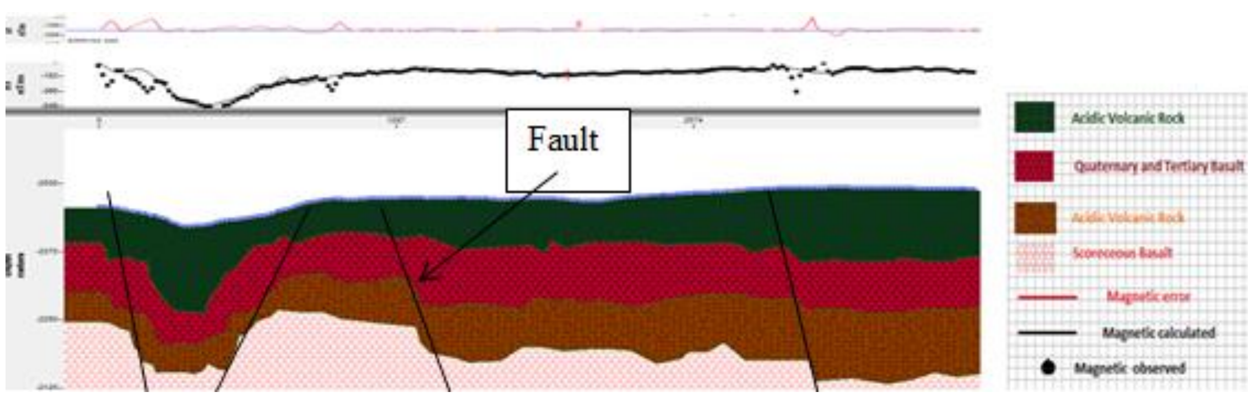


Figure 5.7 Magnetic model of profile-2

5.1.3 Profile three

The line of profile 3 runs over the northern part of the study area. There are four resistivity soundings which are positioned at a distance of 0m, 1000m, 2000m, and 3000m for VES 9, 10, 11 and 12 respectively, from west to east. The Magnetic anomaly and elevation graph, Resistivity pseudo section and magnetic model of profile one is given in figure 5.8-5.10.The line extends from station 0m to station 3620m.The first and the last observation points correspond to the points marked by UTM coordinates 492162E, 1009769N and 495706E, 1009935N within zone 37. The ground elevation is between elevations 2490ma.s.l and 2550ma.s.l.

The profile line three is represented by a resistivity varying from 0.05-100 Ohm-m and this is from decomposed materials to slightly weathered and fractured volcanic rock As we go deeper up to 200 m starting from station 0m to 950m and from 2000m to 3000m a resistivity varies from 20 – 50 Ohm-m decreasing as we go down and this can be interpreted as moderately to slightly fractured, and weathered volcanic rock, this may be partially saturated. Starting from station 950 m and 1700m resistivity value below 15 Ohm-m interpreted as decomposed materials, dry ash dry and clay extending up to a depth of about 400m depth.

Based on the information, the station from 1000 to2000 m is probably expected to be ground water potential zone of the profile. The minimum bed rock is expected between stations 700m and 1000m, around station 2000 and 3000m on which geologic structures are inferred. Apparent resistivity curves of VES9, VES10 VES11 and VES12 are similar and they can be interpreted as the presence of almost similar geologic formation. Figure 5.9 below shows as 2D depth model along profile one obtained from resistivity inversion. The VES interpretation is also based on the apparent resistivity contour given on appendix-A and the resistivity value of some geologic formations given on Appendix-B

The magnetic data of profile three can be interpreted as: The magnetic response of this profile suggests possible geological structures/contacts around stations 100m and 1000m, and is variable having high amplitude and within the zone between 1000m and 3800m the magnetic profile suggests low amplitude which cannot be possible geologic structures/ contact. The magnetic response requires knowledge of local geology for detail interpretation. Fig 5.8 below shows the magnetic anomaly and elevation graph. Fig 5.10 shows the model of the magnetic intensity of profile three.

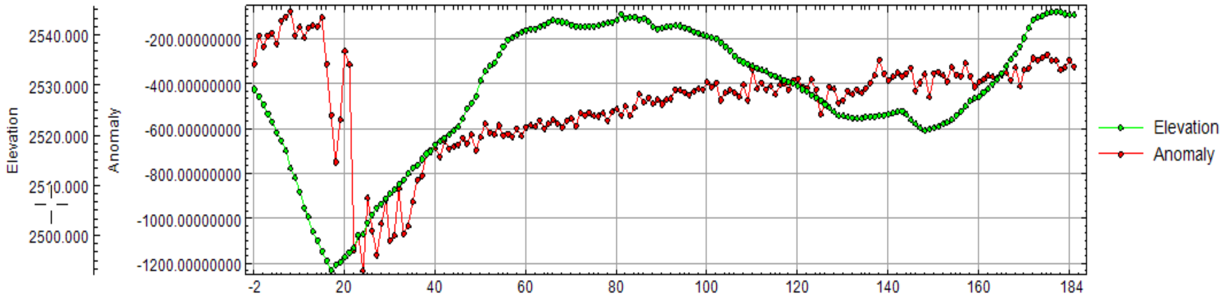


Figure 5.8 Magnetic anomaly and elevation of profile-3

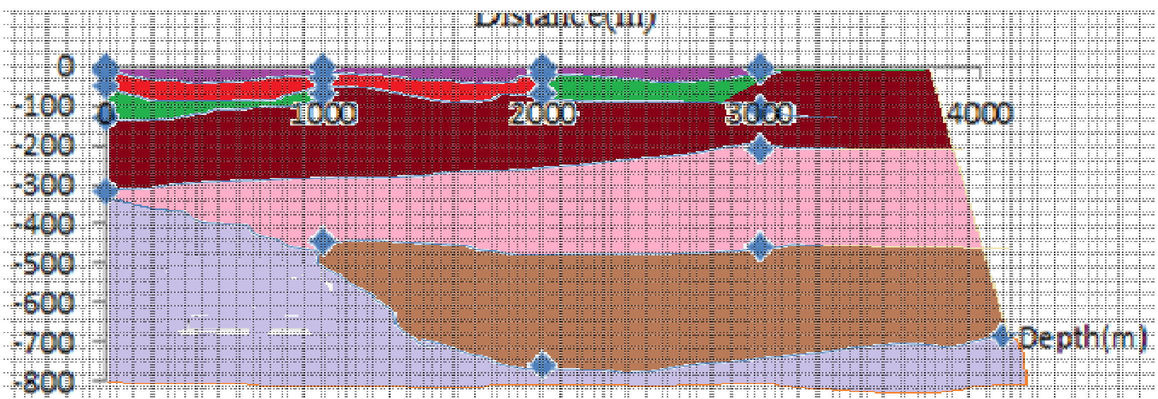


Figure 5.9 2D depth model along profile three obtained from resistivity inversion

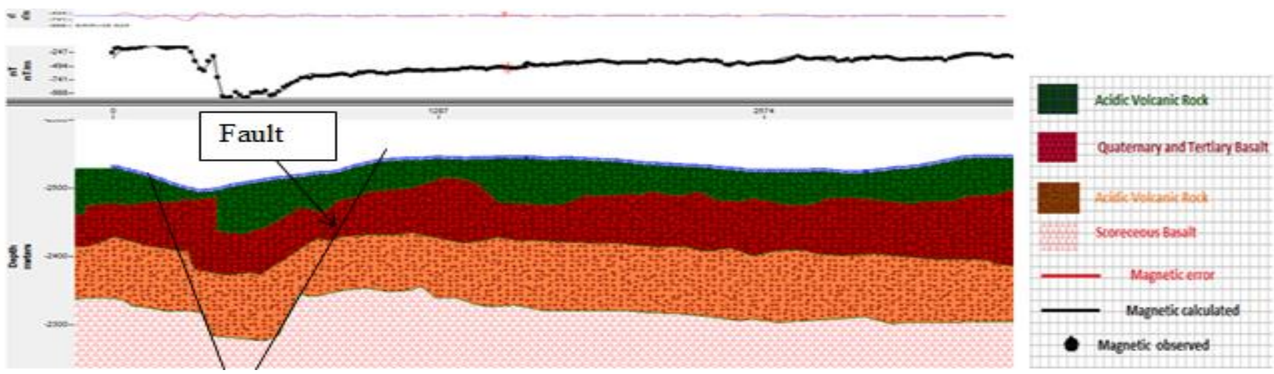


Figure 5.10 Magnetic model of profile-3

5.1.4 Profile four

The last profile that is line 4 also runs over the southern part of the study area in W-E direction. It includes 4 resistivity soundings positioned at a distance of 0m, 1000m, 2000m, and 3000m for VES 13, 14, 15 and 16 respectively. The Magnetic anomaly and elevation graph, Resistivity pseudo section and magnetic model of profile one is given in figure 5.11-5.13. The line extends from station 0m to station 3800m.The first and the last observation points correspond to the points marked by UTM coordinates 491157E, 997939N and 495016E, 998386N within zone 37. The ground elevation is between elevations 2435ma.s.l and 2460ma.s.l.

The upper part of profile four one is represented by a resistivity varying from 50-200 Ohm-m with depth about 200m. This is very high resistivity when compared to Profile 1, profile2, and profile3.and is associated with decomposed materials. The resistivity can be interpreted as Moderately , slightly weathered and fractured volcanic rock, may be partially saturated (50-99ohm-m), and Slightly fractured to fresh volcanic rock (80-200 Ohm-m).

From station 2000m to 3000m starting from the top soil and Starting from station 0 m to 2000 m and depth of about greeter than 600m the resistivity value is below 45 Ohm-m and moderately, weathered and fractured volcanic rock partially saturated, moderately fractured and weathered volcanic rock, probably water saturated and decomposed rock may be water bearing formations are expected with greater depth extension.

On this profile, the area, the station from 2000 m to 3000 m is probably expected to be zone of ground water potential. The depth to bed rock is expected at between stations 1200m and 2000m, and, between stations 2400m and 3000m. The apparent resistivity curves also can be interpreted as VES13, VES14, and VES15 are may have similar geologic formation but VES4 16 may have little difference from the three maybe water bearing zone. Figure 5.12 below shows as 2D depth model along profile one obtained from resistivity inversion. The VES interpretation is also based on the apparent resistivity contour given on appendix-A and the resistivity value of some geologic formations given on Appendix-B.

The magnetic data of profile four can be interpreted as: The magnetic response of this profile suggests possible geological structures/contacts around stations 100m and 1000m, and is variable having high amplitude and within the zone between 1000m and 3800m the magnetic profile suggests low amplitude which cannot be possible geologic structures/ contact. The magnetic response requires knowledge of local geology for detail interpretation. Fig 5.11 below shows the magnetic anomaly and elevation graph. Fig 5.13 shows the model of the magnetic intensity of profile three.

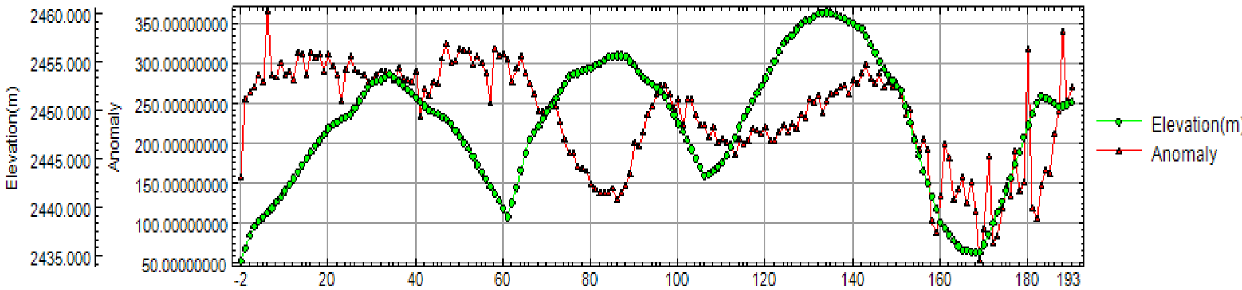


Figure 5.11 Magnetic anomaly and elevation of profile-4

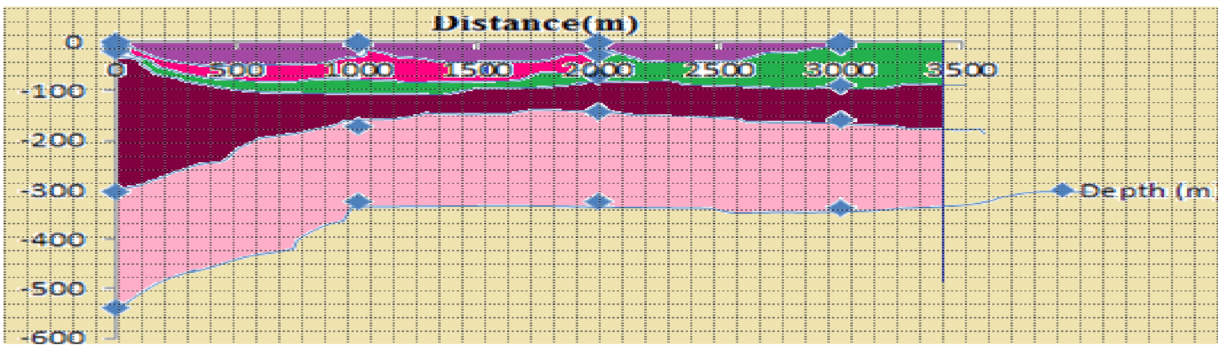


Figure 5.122D depth model along profile one obtained from resistivity inversion

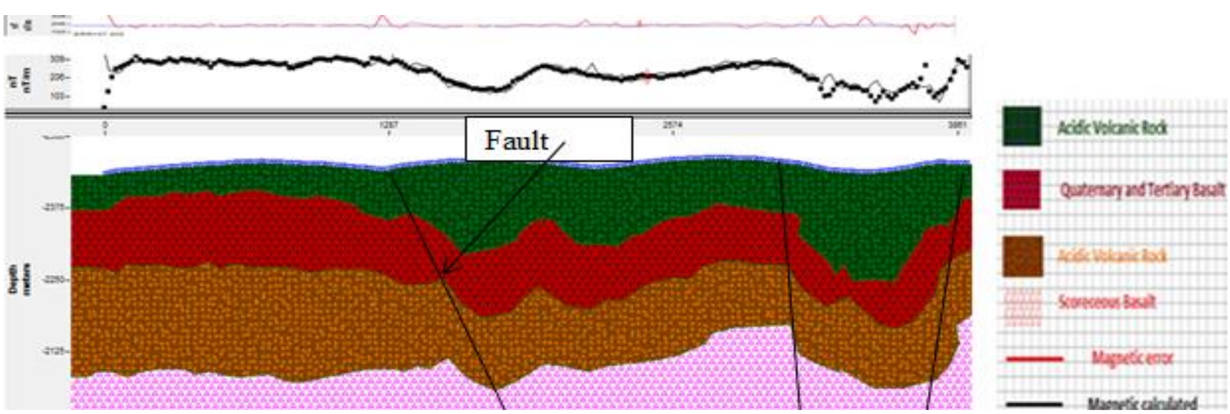


Figure 5.13 Magnetic model of profile-4

5.2 Discussion

Generally the geophysical investigation for ground water exploration of the Legedadi area was based on the two methods of geophysical sciences, namely magnetic survey and vertical electrical sounding methods. The overall work of the project was interpreted from different views. The VES data is interpreted from the apparent resistivity curves, apparent contour, and pseudo-section and also based on the topography of the study area.

Due to this profile one is located at low elevation in comparison to the other three profiles. And profile 2 and three which are found to the north direction are the catchment areas of the profile. The apparent resistivity curve, pseudo-section and the topography of the area indicates that this profile is best for potable ground water potential zone. Generally based on the VES data VES 1 is preferable than the rest three profiles.

The magnetic survey is also interpreted based on different mechanisms including; anomaly curve, trend map, analytic map, magnetic intensity model, magnetic intensity 3D-view, contour map, vertical and horizontal derivative etc. The low magnetic anomaly is interpreted as a possible indication of geologic structures/ fault, fracture, etc. / which are best conduits of ground water circulation. The Analytic signal map tells as the shape size as the direction of the geologic structure if it is done properly. The overall result of the magnetic survey leads to say whether there is geologic structure or not for the geologic formation.

CHAPTER-6

6 CONCLUSION AND RECOMMENDATION

6.1 Magnetic survey

A total of four (4) long magnetic profiles of maximum 4000m were taken across the geological structure of legedadi area. All of the four (4) profiles where oriented about east-west in order to cross and so to detect the possible structure related to groundwater occurrence. Magnetic intensity where recorded across the field of study and negative anomalies station were interpreted for conducting or low resistivity Vertical Electrical Soundings measurements

6.2 VES survey

Based on the resulted magnetic anomalies recorded in the study area, sixteen (16) Vertical Electrical Soundings were probed. All VES were probed at magnetic anomalies in accordance of geophysical, geomorphological and geological appraisal.

The vertical electrical sounding /VES/ survey result have indicated probable potential groundwater aquifer, along profile of the traverse line one in the study area, which is represented by resistivity in the order of 0-40 ohm-m and expected to occur generally below 250m. On this profile identified zones comprising probable groundwater potential is starting from station 0 to 2000m. However, minimum bedrock depth is expected at the beginning of the line about 400m while maximum depth is expected in the vicinities of zones adjacent to major interpreted geological structures. Test wells for deeper groundwater purposes, within the above mentioned zones could be drilled to about 500m.

Generally variable and wide low resistivity zone is observed between throughout profile one .This may correspond to good potential zone of groundwater saturation, possibly corresponding to the location of a regional tectonic structure.

In addition, zones of low resistivity (< 10 ohm-m) at depth are interpreted as comprising volcanic rocks, highly decomposed in to clay, or presence of ash and or tuff. These zones may be less productive and create (possible collapse) problems during drilling.

From groundwater perspective point of view all the four test drill sites are favorable. However, from productivity (higher degree of fracturing as indicated by the resistivity values of the intermediate units) and depth

Magnetic Survey

- Magnetic survey along profile line1, profile line 2, profile line three and profile line 4 has defined a number of geological contacts/structures which may be favorable for the location of deep potable ground water wells. The location of these structures is described in each section of the results of the magnetic survey.

6.3 Recommendation

Based on the main findings the thesis work, the following recommendations are given:

I strongly recommend that the very low resistivity formations on the study area are not good for drilling wells. Because, it requires a very systematic way of well drilling because of collapse unless it happens due to the presence of highly decomposed materials in to clay, ash and tuff.

It is recommended to collect different types of geophysical data. The data collection includes MT data, time domain electromagnetic data, and other geophysical methods. Magnetic model and 2D- depth model can be used in order to take good measurement. Further survey and research is recommended on the study area.

The area can serve as a survey practice area for Addis Ababa University, earth science department, for further investigation by using different geological and geophysical methods because it is accessible area and is very near to the University.

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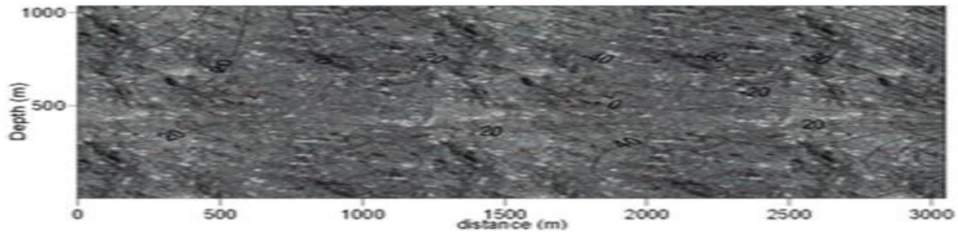
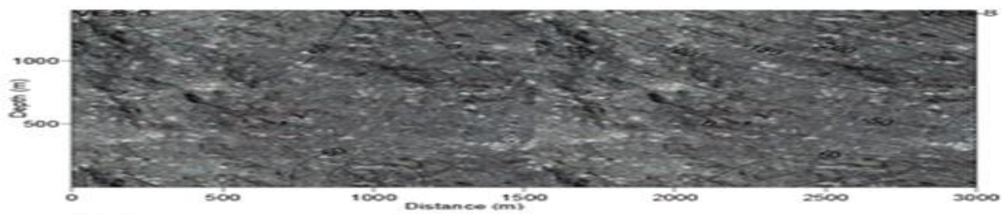
Appendix-A

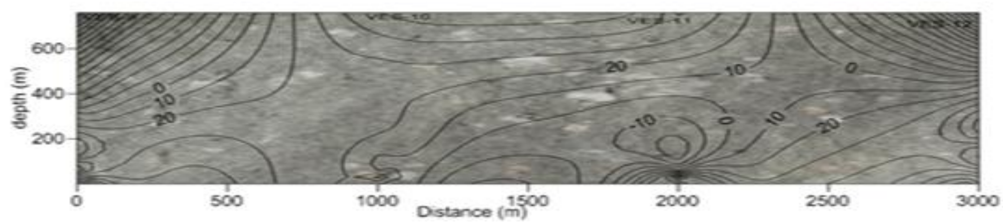
Apparent resistivity contour found after inversion for profiles 1, 2, 3 and 4



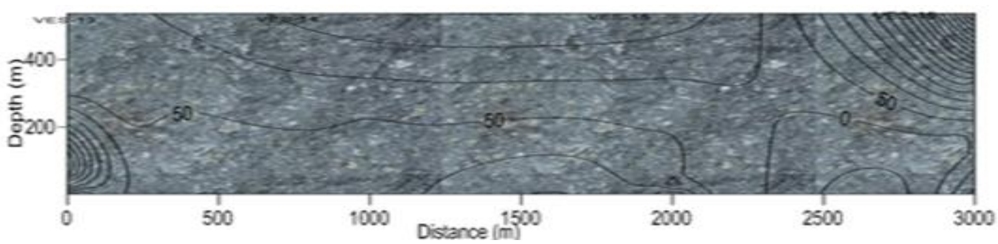
Profile-1



profile-2



profile-3



profile-4

Appendix-B

No.	Estimated resistivity range (Ω-m)	Main Geological formation	Description	Remarks
1	2-20	Clay		some times wet and weathered and intercalated with silt
2	20-90	Top soil and unconsolidated sediment	The unconsolidated sediment is comprised of sand, silt and gravel at places	This unit is occasionally water bearing
3	100-150	Acidic rock	Rhyolites, ignimbrite and trachyte weathered and fractured at places	Saturated and water bearing at places
4	150-250	Basic rock	Basalt which is fractured and weathered and sometimes Scoraceous	Water bearing when it is fractured
5	250-500	Basic rock	Basalt which is mostly fresh and un weathered	Dry to slightly water bearing

Resistivity value of some geologic formations taken from (WWDSE)